Energy Research and Development Division
FINAL PROJECT REPORT

WATER AND WASTEWATER UTILITY ENERGY RESEARCH ROADMAP

Prepared for: Water Research Foundation, New York State Energy and Research Development Authority and California Energy Commission

Prepared by: MWH Americas, Inc.

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Water and Wastewater Utility Energy Research Roadmap is the final report for the Water and Wastewater Utility Energy Research Roadmap project (contract number 500-10-056), project number #4356 conducted by MWH Americas, Inc. The information from this project contributes to Energy Research and Development Division's Industrial/Agricultural/Water End-Use Energy Efficiency Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

Water and wastewater utilities are increasingly looking for innovative and cost effective energy management opportunities to reduce operating costs, mitigate contributions to climate change, and increase the resiliency of their operations. The Water Research Foundation, the California Energy Commission and the New York State Energy Research and Development Authority jointly funded this project to assess the current state-of-knowledge on energy management, concepts and practices at water and wastewater utilities; understand the issues, trends and challenges to implementate energy projects; identify new opportunities to set a direction for future research; and develop a roadmap for energy research that includes a list of prioritized research, development, and demonstration projects on energy management for water and wastewater utilities.

The project was conducted through completing a literature review, a questionnaire among water and wastewater utilities and two facilitated workshops attended by 60 invited experts. The workshops were organized around four different focus areas of research and a total of 50 project concepts were identified. From these fifty project concepts, 32 projects were recommended for inclusion in the energy research roadmap based on these prioritization criteria: their likelihood of implementation at larger scale, timeliness of research needs, environmental and economic benefits, and risk management. An overall roadmap with 24 “stops” has been developed with each stop representing a potential funding opportunity prioritized (from highest to lowest)from the projects ranked by the workshop participants. This roadmap now replaces the previous one developed in 2004 and may be used as guidance for allocating energy research funds for the next 5-10 years.

Keywords: Energy, Roadmap, Research, Water Utilities, Wastewater Utilities, Water Reuse, Desalination, Energy Efficiency, Energy Recovery, Energy Generation, Energy Management.

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Background

The water industry faces challenges associated with escalating energy costs due to increased energy consumption and higher energy unit prices. Increased energy consumption is affected by energy-intensive treatment technologies needed to meet more stringent water quality regulations, growing water demand, pumping over longer distances, and climate change. More desalinated water to augment water supply shortages and the growth of groundwater augmentation is also anticipated.

The strategies for energy management in water and wastewater utilities vary substantially from energy cost reduction by managing electric tariffs/sources, to energy consumption reduction through energy efficient operations. energy neutrality through on-site energy recovery to reduce costs, mitigating contributions to climate change, and increasing resiliency of operations. The New York State Energy Research and Development Authority (NYSERDA), the California Energy Commission (Energy Commission), Water Research Foundation (WRF), United States Environmental Protection Agency (EPA) and the Electric Power Research Institute (EPRI) have sponsored numerous energy programs to help water and wastewater utilities on energy management issues. In 2004, WRF and the Energy Commission co-funded developing an energy research roadmap for water and wastewater utilities, identifying 44 research project concepts, with eight being co-funded by WRF and the Energy Commission, and more funded by other entities. In the last 10 years, research and technology have advanced and water and wastewater operations, including desalination and water reuse, have become more integrated. This project lays a foundation to understand the trends and issues from the past and ongoing research projects and sets a direction for future research. This project explored new research agendas and structured new and innovative research questions that will enable advancements in energy research for water and wastewater utilities.

Project Purpose

The specific objectives of this study were to:

- Assess the current state-of-knowledge on energy management and efficiency concepts and practices at water and wastewater utilities;
- Understand the issues, trends, and challenges for implementation of energy projects at water and wastewater utilities, and identify new opportunities to set up a direction for future research; and
- Develop a roadmap for energy research that will include a list of prioritized research, development, and demonstration projects on energy management for water and wastewater utilities.

Approach

The following tasks were performed to address the objectives of this research.

Literature Review

A literature review was conducted to provide a comprehensive and critical review of the current state of knowledge on energy management issues and opportunities in the water and wastewater sectors and to identify knowledge gaps and research needs that will help develop a five to ten year research plan for water and wastewater utilities. The project team leveraged a variety of gray and peer-reviewed publications by various agencies and organizations to identify and summarize ideas on specific energy areas that benefit the water and wastewater industries, including desalination and water reuse.

Utility Questionnaire

A web-based questionnaire was developed to solicit input from experts on the focus and direction of the workshop. Additional information collected from the questionnaire included examples of recent energy projects implemented or planned by various organizations and the barriers and challenges faced by the organizations in implementing an energy projects.

The questionnaire was distributed to the workshop participants and to other water and wastewater utility personnel through the WRF newsletter in order to solicit input from non-workshop participants. A total of 36 responses from various organizations across the United States, one from Canada and two from Australia were received.

Workshops

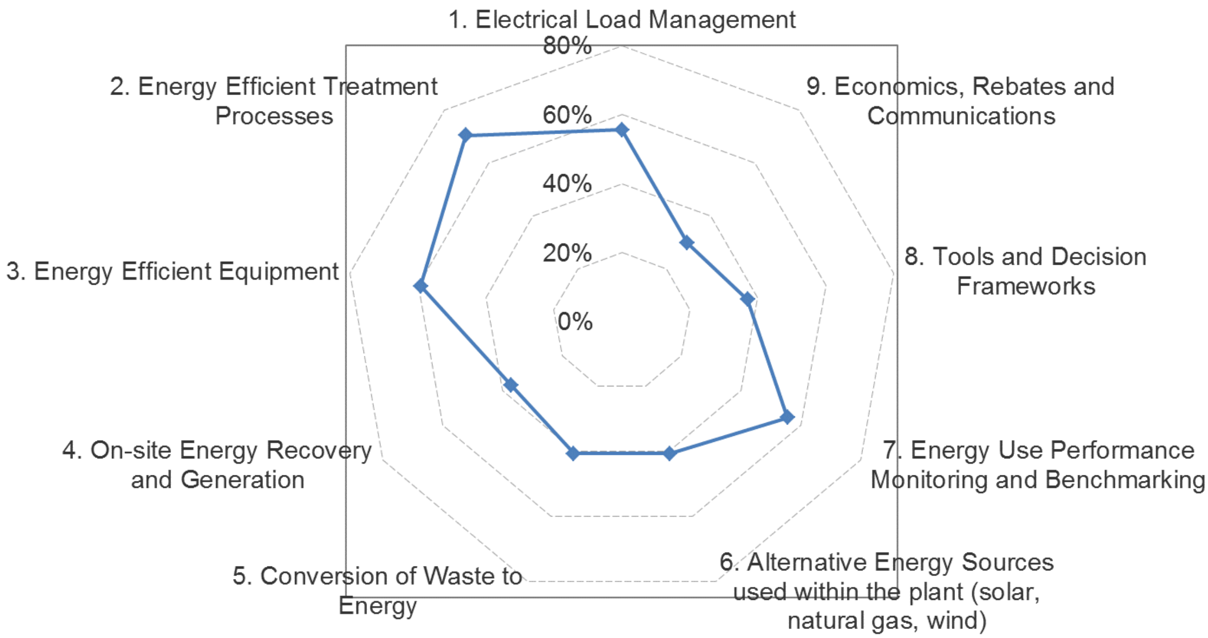
Two facilitated workshops were convened on November 5-6, 2014 at the New York City Department of Environmental Protection (NYCDEP) location in Flushing, New York and on November 19-20, 2014 at the MWH Americas office in Pasadena, California.

On the first day of the two-day workshop, the agenda included plenary presentations from the project team and other invited organizations (i.e., United States Department of Energy and NYCDEP). The participants then divided in four breakout groups, reflecting the research focus areas: energy management, energy efficient equipment, energy efficient processes, and energy and resource recovery. During Breakout Session 1, each group assessed the current state of knowledge on various research topics, and identified the challenges/issues/trends and the associated opportunities/solutions. During Breakout Session 2, each group identified at least five energy research project concepts under each focus area. This discussion continued on the second day of the workshop, when each group prioritized the research projects.

Results and Conclusions

The study concluded that the water/wastewater utility’s interests in energy research vary substantially. According to the questionnaire findings of this study, the water/wastewater industry will benefit from further research in the nine energy management areas with highest needs identified in the “energy efficient treatment process” (70 percent), “energy efficient equipment” and “electrical load management” and “energy use performance monitoring and benchmarking”areas (less than 60 percent).

Figure ES: 1 Percentage of respondents indicating high benefit from further research in nine different energy management areas

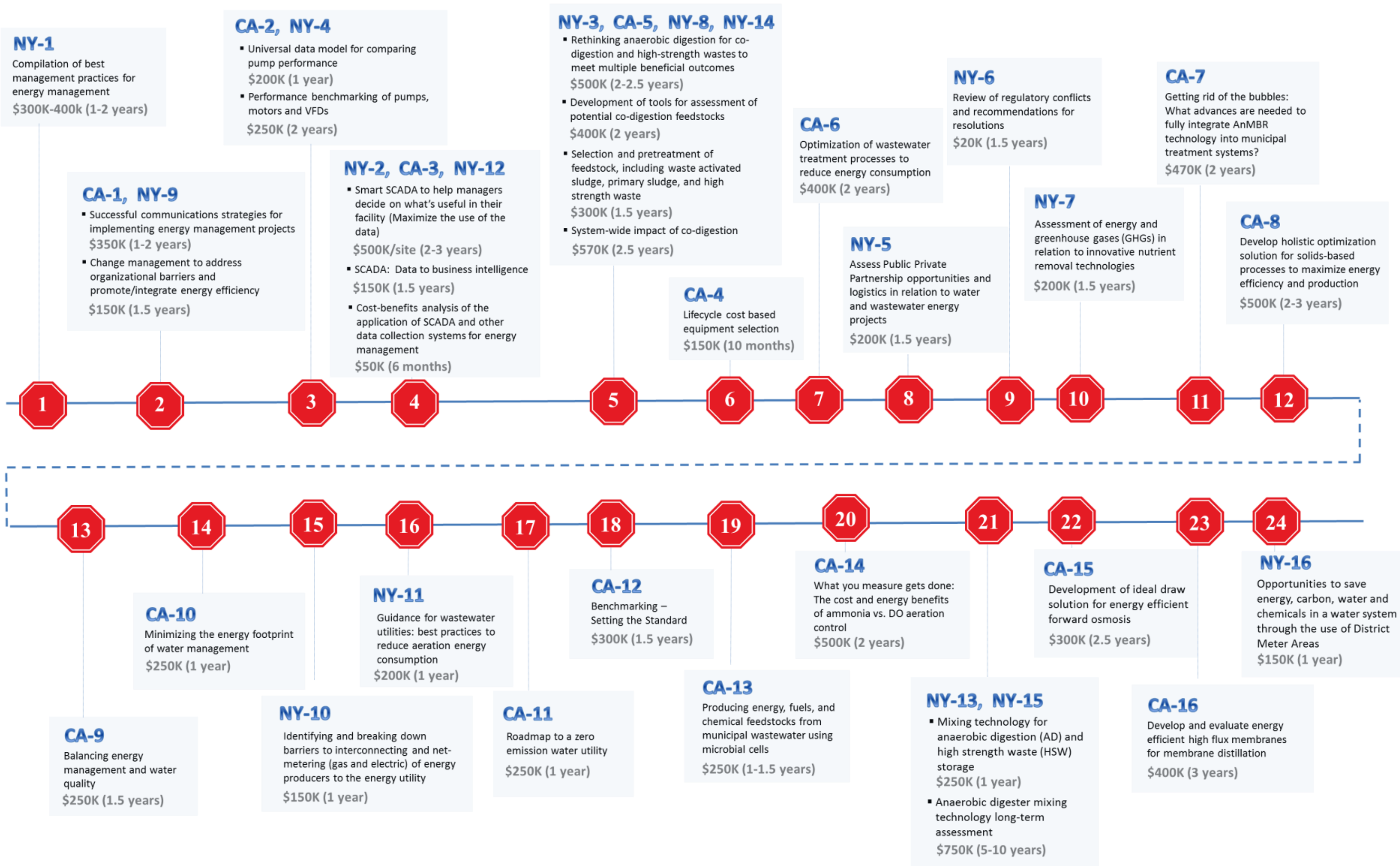


A total of 50 project concepts were developed to address contemporary energy research needs organized around four different focus areas of research. A total of 50 project concepts were identified as follows: 11 projects on energy management, 13 projects on energy efficient equipment, 14 projects on energy efficient processes, and 12 projects on energy and resource recovery.

Out of the 50 project concepts, 32 projects were recommended for inclusion in the energy research roadmap based their likelihood being implemented at larger scale, timeliness of research needs, environmental and economic benefits, and risk management. These projects represent an estimated $9.8 million in total funding opportunities, and the teams developed project descriptions including objectives, background, research approach, schedule, and budget. These projects and the areas of research that they represent will enhance implementing energy programs and improving energy management in water and wastewater utilities.

After assessing the similarities of the outcomes of the two workshops, an overall roadmap with a total of 24 "stops" was developed (Figure 1). Each stop represents a potential funding opportunity sorted by priority (from highest to lowest). "Stop 1" through "Stop 12" includes projects with higher scores (List A)."Stop 13" through "Stop 24" represent projects that received lower scores by the participants (List B). In five instances, the roadmap identifies opportunities to group or combine projects with similar objectives or expected outcomes regardless of their initial score. In consideration of the different foci, overall objectives and intents of the original projects, the descriptions of these projects were not merged.

Figure ES.2: Energy Research Roadmap



Note: Each project title is represented by the workshop location and the ranking of the project at that location (e.g., NY-2 is the second ranked project from the New York workshop)

Recommendations

- The energy research roadmap and the individual project descriptions that resulted from this study should be considered as guidance to develop future request for proposals by the WRF and the liaison agencies. Prior to releasing the request for proposals, the findings of the recently completed and on-going projects that were available at the time of this study, should be properly reviewed to avoid any potential duplication of research and to ensure that the future projects are built on the past and current work.
- More collaboration among the research organizations and other entities (e.g., industry, government, and regulatory organizations) should be encouraged to perform cooperative research and better leverage of the project funding. The published reports from one research organization should be shared with the others in a timely manner and the published reports should be advertised to the water/wastewater industry through a common platform (e.g., a joint energy research newsletter) so that the reports can be disseminated to a wider audience.
- Due to shifts in priorities and the rapid development in research and technologies, it is recommended that the energy research roadmap be updated every five years.

CHAPTER 1 : Introduction

1.1 Background

The water industry faces challenges associated with escalating energy costs due to increased energy consumption and higher energy unit prices. Increased energy consumption is affected by energy-intensive treatment technologies needed to meet more stringent water quality regulations, growing water demand, pumping over longer distances, and climate change (GWRC, 2008). Moreover, the need for desalinated water to augment water supply shortages and the growth of groundwater augmentation is also anticipated (House, 2007). The same study by the Energy Commission estimates the demand for electricity in the water industry to double in the next decade. The water sector has shown only a limited response in implementing improvements that effectively address sustainability issues due to insufficient modernization, the presence of numerous regulatory and economic hurdles, and poor integration of energy issues within the water policy decision-making process (Liner and Stacklin, 2013; Rothausen and Conway, 2011). In realization of these issues and their impact on the water-energy nexus, water and wastewater utilities have started investigating state or federal grant funding availability, and the need for capital replacement and utility leadership vision, and the implementation of incentivized energy programs, such as electric utilities' incentive programs (Rothausen and Conway, 2011). Efficient energy use also needs to be further integrated into water utility management through identification of research opportunities that promote sustainable energy solutions in the water and wastewater sector.

Water and wastewater companies' investments in research and development have drastically decreased in recent years and government research and development schemes in both the United States and the United Kingdom for the water sector are very limited compared with those performed in the energy sector (Rothausen and Conway, 2011). There has been, however, an increasing awareness of the importance of energy management at water and wastewater utilities, the need for making better resource management and investment decisions, and the need to integrate energy management into decision making. Energy research and development in the water and wastewater sector has been conducted by a wide variety of public and private organizations. Several non-profit organizations including the Water Research Foundation (WRF), the Water Environment Research Foundation (WERF), the WateReuse Research Foundation and the Electric Power Research Institute (EPRI), have greatly contributed to the advancement of research and development in these sectors. In addition, governmental agencies, such as the United States Environmental Protection Agency (EPA), the United States Bureau of Reclamation, the United States Department of Energy (DOE), and the United States Army Corps of Engineers are actively involved in various research efforts. Consulting firms, academics and equipment manufacturers are also conducting significant water and wastewater Research and Development (R&D) efforts and have produced energy efficiency guidebooks for the water and wastewater industry (Arzbaecher et al., 2013). Collaboration among these entities is occurring in order to better leverage project funding.

The WRF has been active in investigating and developing research opportunities that address the nexus between energy and water and the approaches needed for more sustainable management of these resources. In 2004, the WRF, in collaboration with the Energy Commission, provided direction for the R&D activities of the California Energy Commission's Public Interest Energy Research program in the report *Water and Wastewater Industry Energy Efficiency: A Research Roadmap* (Means, 2004). Forty-four project ideas were developed in eight primary focus areas related to energy use in water and wastewater utilities. From the Roadmap, WRF and the Energy Commission co-funded eight high priority research projects and other high priority projects were funded by other organizations (Table 1.1).

Since 2008, the New York State Energy Research and Development Authority (NYSERDA) has collaborated with WERF towards furthering research and information transfer within the wastewater sector on innovative energy efficiency and on-site electricity generation technologies and processes. NYSERDA has also collaborated with WRF on five energy efficiency and climate change mitigation projects (Table 1.2). Through these research programs, energy recovery and generation, the optimization of energy use, the use of more efficient operations and technologies, and alternative energy portfolios are under development (GWRC, 2008).

WERF started to address research needs of the wastewater industry in 1989 and recently began focusing on finding solutions to inter-related challenges concerning i) nutrient recovery, specifically in regards to transitioning from a treatment based industry to a resource recovery one that is both economically and environmentally sustainable; ii) energy production and efficiency practices that result in energy self-sufficiency for wastewater treatment plants; and iii) sustainable systems that integrate management of wastewater, stormwater, drinking water and source water (VWEA, 2013). Recently, the Water Environment Federation (WEF) in collaboration with other water and power industry leaders developed an energy roadmap to guide water and wastewater utilities of all sizes towards sustainable energy management and the "Smart Grid" technology concept. A series of high level strategic best practices were selected in different focus areas. The roadmap provides guidance for utilities seeking to implement energy efficiency programs or to achieve a goal of net zero energy and neutrality (Liner and Stacklin, 2013).

The American Council for an Energy-Efficient Economy (ACEEE) also developed A Roadmap to Energy in the Water and Wastewater Industry in collaboration with EPA, WERF, the Energy Commission, the Iowa Energy Center (IEC), NYSERDA and Alliance to Save Energy (ASE) (ACEEE, 2005). A research strategy workshop was organized by the Global Water Research Coalition (GWRC) in 2008 to review the energy knowledge and ongoing activities in the water and wastewater sectors in order to develop a phased research strategy that targets an energy and carbon footprint neutral urban water cycle by 2030 (GWRC, 2008).

Figure 1-1 shows the timeline of key selected research projects on energy management that were carried out by some of these organizations during the last three decades.

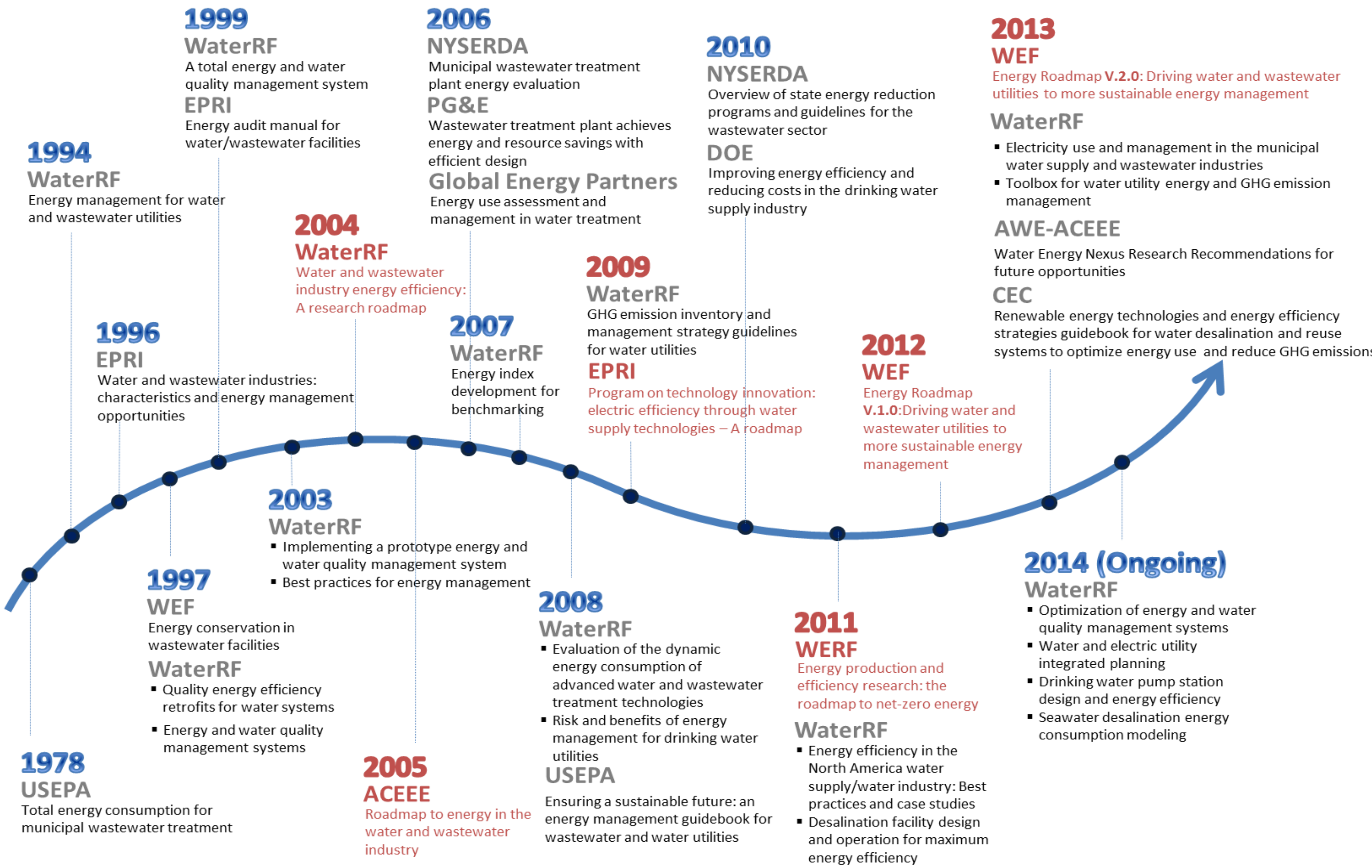
Table 1.1 WRF research roadmap projects co-funded with the Energy Commission

Report Name	Date Published	Project #/ Report #
Water and Wastewater Industry Energy Efficiency: A Research Roadmap	2004	#2923/2923
Energy Index Development for Benchmarking Water and Wastewater Utilities	2007	#3009/91201
Zero Liquid Discharge for Inland Desalination	2007	#3010/91190
Desalination Research Database	Not published	Not published (#3055)
Risks and Benefits of Energy Management for Drinking Water Utilities	2008	#3058/91200
Evaluation of Dynamic Energy Consumption of Advanced Water and Wastewater Treatment Technologies	2008	#3056/91231
Water Consumption Forecasting to Improve Energy Efficiency of Pumping Operations	2007	#3066/91189
Desalination Facility Design and Operation for Maximum Efficiency	2011	#4038/4038
Optimization of Energy and Water Quality Management Systems for Drinking Water Utilities	In publication (2015)	In publication (#4271)

Table 1.2 WRF Energy management and climate change projects co-funded with NYSERDA

Report Name	Date Published	Project #/ Report #
Energy Efficiency Best Practices for North American Drinking Water Utilities	2011	#4223
Toolbox for Water Utility Energy and Greenhouse Gas Emission Management	2013	#4224
Changing Organizational Culture to Promote Sustainable Water Operations: A Guidebook for Water Utility Sustainability Champions	2013	#4264
Developing Robust Strategies for Climate Change and Other Risks: A Water Utility Framework	2014	#4262
Water and Electric Utility Integrated Planning	In Progress	#4469

Figure 1.1 Timeline of key past and ongoing research projects on energy management carried out by various organizations



1.2 Objective

In 2004, WRF and the Energy Commission co-funded the development of an energy research roadmap for water and wastewater utilities. That effort resulted in the identification of 44 research project concepts, eight of which were subsequently co-funded by WRF and the Energy Commission , and many more funded by other entities. In the last ten years, research and technology have advanced, and water and wastewater operations, including desalination and water reuse, have become more integrated. In order to advance the existing knowledge on energy management, it is a timely research need to understand the trends and issues from the past and ongoing research projects and to reaffirm a direction for future research. Thus, the specific objectives of this project were to seek collaborations among various entities such as research organizations, academia, industry, government, private and non-profit organizations to explore new research agendas and to structure new and innovative research questions that will enable advancements in energy management and efficiency for water and wastewater utilities. The specific objectives of this study were to:

- Assess the current state of knowledge on energy management and efficiency programs, concepts and practices at water and wastewater utilities;
- Understand the issues, trends, and challenges for implementation of energy projects at water and wastewater utilities;
- Identify new opportunities to focus the direction for future research; and
- Develop a roadmap for energy research that will include a list of prioritized research, development, and demonstration projects on energy management for water and wastewater utilities.

1.3 Research Approach

The following tasks were performed in order to address the objectives of this research:

1.3.1 Literature Review

A literature review was conducted to provide a comprehensive and critical review of the current state of knowledge on energy management issues and opportunities in the water and wastewater sectors and to identify knowledge gaps and research needs that will help develop a five to ten year research plan for water and wastewater utilities. The project team leveraged a variety of gray and peer-reviewed publications by various agencies and organizations to identify and summarize ideas on specific energy areas that are beneficial to the water and wastewater industries, including desalination and reuse.

1.3.2 Utility Questionnaire

A web-based questionnaire was developed to solicit input from experts on the focus and direction of the workshop. Additional information collected from the questionnaire included examples of recent energy projects implemented or planned by various organizations and the barriers and challenges faced by the organizations in implementing the energy projects.

The questionnaire was distributed to the workshop participants and to other water and wastewater utility personnel through the WRF newsletter, *Water Currents*, in order to solicit input from non-workshop participants. A total of 36 responses from various organizations across the United States and Australia were received. The outcomes of the survey have been embedded within the discussion in Chapter 2 and Chapter 3.

1.3.3 Workshops

Two facilitated workshops were convened on November 5-6, 2014, at the New York City Department of Environmental Protection (NYCDEP) offices in Flushing, New York and on November 19-20, 2014, at the MWH Americas office in Pasadena, California.

The project team, in coordination with WRF, the Energy Commission, NYSERDA and a Professional Advisory Committee (PAC) formed for this work, identified a list of 65 participants with expertise in energy management, energy generation and recovery, energy policy and economics, water and wastewater treatment, treatment technologies and other related fields for participation to the workshops. Table 1.3 shows the distribution of the workshop participants based on different sectors.

Table 1.3 Distribution of workshop participants

	Water/ Wastewater Utilities	Academia	Organizations/ Agencies/ Sponsors	Electric utilities	Regulators	Vendors	Consultants
New York	14	2	9	0	2	1	5
California	17	1	4	1	1	2	6

The workshop participants were provided with a pre-workshop package which included a literature review summary on energy management in water and wastewater utilities and related research needs as a background reference document for the participants.

The first day of the two-day workshop, started with plenary presentations from the project team, the funding organizations of this study (WRF, NYSERDA and the Energy Commission) and other invited organizations (i.e., DOE and NYCDEP). The participants were then divided in four breakout groups, according to the research areas presented in Chapter 3. Each group was assigned a leader, a scribe, and a reporter. The leader ensured that the topics were covered and summarized within the allotted timeframe; the scribe captured and recorded the discussion items; and the reporter summarized the major points and presented them back to the entire group. The breakout groups met in two different breakout sessions, Breakout Session 1 and Breakout Session 2. During Breakout Session 1, each group assessed the current state of knowledge on various research topics in their assigned focus area, and identified the challenges/issues/trends and the associated opportunities/solutions. During Breakout Session 2, each group identified at least five energy research project concepts in their assigned focus area. The discussion continued on the second day of the workshop, when each group prioritized the research projects. The approach used for the identification and prioritization of the research projects and for the energy research roadmap development is presented in detail in Chapter 3 and Chapter 4.

1.4 Organization of the Report

This report is organized into the following chapters:

Chapter 1: Introduction;

Chapter 2: Energy Research for Water and Wastewater Utilities: Past and Present;

Chapter 3: Development of the Project Concepts;

Chapter 4: Energy Research Prioritization and Roadmap Development.

Chapter 5: Summary and Recommendations.

Information obtained from an extensive literature review, a questionnaire among water and wastewater utilities, and two workshops were utilized to develop the report.

CHAPTER 2 :
Energy Research for Water and Wastewater Utilities Past and Present

The objective of this chapter is to present the current state of knowledge on energy management issues and opportunities in the water and wastewater sectors and to identify knowledge gaps and research needs that will help develop a five to ten year research roadmap for water and wastewater utilities. This chapter primarily focuses on research conducted in the United States and a short summary on the outcomes of the survey distributed to experts as part of this project.

2.1 Energy Management Opportunities in Wastewater Treatment and Water Reuse

Currently, there are over 15,000 municipal wastewater treatment plants (WWTPs), including 6,000 publicly owned treatment works (POTWs) providing wastewater collection and treatment services to around 78% of the United States' population (Mo and Zhang, 2013; Spellman, 2013).

According to the report published by EPRI and the WRF (Arzbaecher et al., 2013) in 2008 municipal wastewater treatment systems in the United States used approximately 30.2 billion kilowatt hours (kWh) per year, or about 0.8% of total electricity used in the United States. These WWTPs are becoming large energy consumers and they can require approximately 23% of the public energy use of a municipality (Means, 2004). Typical wastewater treatment operations have a total average electrical use of 500 to 4,600 kWh per MG treated, which varies depending on the unit operations and their efficiency (Kang et al., 2010; WEF, 2009; GWRC, 2008; NYSERDA, 2008a). Treatment-process power requirements as high as 6,000 kilowatt hours per million gallons (kWh/MG) are required when membrane bioreactors are used in place of activated sludge or extended aeration (Crawford & Sandino, 2010).

Approximately 2,000 million kWh of electricity are consumed annually by wastewater treatment plants in California (Rajagopalan, 2014). Energy use by these utilities is affected by influent loadings and effluent quality goals, as well as process type, size and age (Spellman, 2013). The majority of energy use occurs in the treatment process, for aeration (44%) and pumping (7%) (WEF, 2009). In major Australian WWTPs, the pumping energy for wastewater facilities ranged from 16 to 62% of the energy used for treatment (Kenway et al., 2008). In New York, the wastewater sector uses approximately 25% more electricity on a per unit basis (1,480 kWh/MG) than the national average (1,200 kWh/MG) due to the widespread use of energy intensive activated sludge, as well as compliance with stringent New York State effluent limits, which often require tertiary or other advanced treatment. Additionally, the predominance of combined (stormwater and wastewater) sewer systems at the largest facilities, coupled with significant inflow and infiltration, result in extremely large variations in influent flow rates and loading, making efficient operations difficult (Yonkin et al., 2008).

Different types of energy are available in wastewater that can be used or converted to achieve energy neutrality at wastewater treatment plants. Raw wastewater has, in fact, a thermal, hydraulic, and chemical energy content that exceeds the electricity requirements for treatment by a factor of 9.3 to 1 that can be recovered to achieve net positive power at wastewater treatment facilities (Cooper et al., 2011). Wastewater also contains heat energy which is governed by the specific heat capacity of water (thermal energy), energy stored in organic chemicals (chemical or calorific energy), potential and kinetic energy from water elevation and movement, respectively (hydraulic energy). Various energy programs, practices and technologies can help capture wastewater's total energy potential and reduce the overall energy requirements for treatment (McCarty et al., 2011). These programs aim to attain operational sustainability, target cost/energy savings and net positive energy balance at wastewater treatment facilities.

The greatest potential for net positive energy recovery occurs at larger facilities, which are only a small percentage of the treatment works nationwide, but treat a large percentage of the nation's wastewater. By achieving energy neutrality and eventually energy positive operations at larger facilities, the energy resources in the majority of domestic wastewater can be captured. This principle guided WERF to prepare a program to conduct the research needed to assist treatment facilities over 10 million gallons per day (MGD) to become energy neutral (Cooper et al., 2011). Energy self-sufficiency has been attained at a wastewater plant in Strass, Austria, where the average power usage is approximately 1,000 kWh/million gallon (MG) treated, which is also the approximate electricity generation from the sludge (Kang et al., 2010). The design employs two stages of aerobic treatment, with innovative controls, where biosolids generated in the two stages are thickened and anaerobically digested, with gas recovery and power generation. The centrate from the dewatering operation is treated in a sequencing batch reactor using the DEamMONification (DEMON) process to reduce the recirculation of nutrients to the head of the plant.

The importance of the scale of a facility in understanding the different strategies that may be implementable for the technology or service options available is pointed out in a recent report (AWE and ACEEE, 2013). It is important that energy management best practices are defined with consideration of specific plant size or treatment process. The largest per unit users of energy are, in fact, small water and wastewater treatment plants that treat less than 1 MGD, as well as those that employ an activated sludge with or without tertiary treatment process.

Further details on the different energy management programs, strategies, technologies and related research and development needs are highlighted in the following sections.

2.1.1 Electrical Load Management Strategies

Wastewater treatment facilities have significant electricity demand during periods of peak utility energy prices. An effective energy load management strategy can help wastewater utilities to significantly reduce their electricity bills. A number of electrical load management opportunities are available to wastewater utilities (Table 2.1), notably by flattening the energy demand curve, particularly during peak pricing periods and by shifting major electrical demand to lower cost tariff blocks (e.g., overnight), for intra–day operations, or from season to season where long- or short-term wastewater or sludge storage is practical (NYSERDA, 2010).

Wastewater treatment facilities have the potential to benefit from electric utility demand response (DR) opportunities, programs and tariffs. Although the use of integrated energy load management systems for wastewater utilities is still in its infancy, some wastewater utilities have begun implementing strategies that provide a foundation for participation in demand response programs. Such implementations are thus far limited to control pumping in lift stations of wastewater collection systems in utilities equipped with sufficient storage (Thompson et al., 2008). Wastewater treatment processes may offer other opportunities for shifting wastewater treatment loads from peak electricity demand hours to off-peak hours, as part of Demand Management Programs (DMPs), by modulating aeration, backwash pumps, biosolids thickening, dewatering and anaerobic digestion for maximum operation during off-peak periods. Recently, wastewater utilities, such as the Camden County Municipal Utilities Authority, have developed a computerized process system that shaved the peaks by avoiding simultaneous use of energy-intensive process units, to the maximal extent possible, thereby minimizing the peak charge from the energy provider (Horne and Kricun, 2008). In addition, the East Bay Municipal Utilities District has implemented a load management strategy which stores anaerobic digester gas until it can be used for power generation during peak-demand periods. Another opportunity for shifting electrical loads from on-peak to off-peak hours is over-oxygenating stored wastewater prior to a demand response event, then turning off aerators during peak periods without compromising effluent quality (Thompson et al., 2008). For a wastewater facility to successfully implement demand response programs, advanced technologies that enhance efficiency and control equipment are needed, such as a comprehensive and real-time demand control from centralized computer control systems that can provide an automatic transfer switch to running onsite power generators during peak demand periods, in accordance with air quality requirements (Thompson et al., 2008).

An interesting opportunity for reducing energy use in municipal wastewater treatment is to improve storm water management (Lekov, 2010). The adoption of stormwater treatment only at CSO communities can reduce energy consumption for wastewater treatment systems due to reductions in volume at the treatment plant and reduction in volumes requiring pumping in the combined sewer collection system.

Table 2.1 Opportunities for electrical load management in wastewater treatment facilities

Electrical Load Management Strategies	
Electric load shifting	▪ Reduce aeration during mid-day ▪ Provide effluent storage ▪ Over-oxygenation of stored wastewater ▪ Reschedule facility processes to electricity off-peak hours
Electric load shedding	▪ Operate at reduced equipment capacity ▪ Shut down equipment ▪ Utilize standby generators
Alternative fuels	▪ Store gas generated for use during peak-price electrical period
Flow equalization	▪ Store influent or sludge to equalize flow

R&D opportunities in load management and DR have been identified in the report by EPRI and the WRF (Arzbaecher et al., 2013) report. In general, there is little comprehensive research on industry-specific energy use data that can assist wastewater utilities in targeting DR activities. Identification and estimates of DR potential in wastewater systems, associated economics and related guidelines are lacking. An initial study conducted by the Lawrence Berkeley National Laboratory (LBNL) included guidance for wastewater facilities seeking to target energy efficiency and DR strategies using equipment and facility controls (Lekov, 2010). Future research opportunities in this topic are captured in the Research Opportunities section presented below.

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Energy Load Management

- Understanding current and potential DR implementation opportunities in wastewater treatment facilities and existing control capabilities.
- Developing a DR Quick Assessment tool that can assess wastewater treatment performance within some range of performance criteria for DR program implementation.
- Increasing the reliability and cost effectiveness of DR programs by scaling and standardizing the implementation strategies;
- Acquiring better understanding of how facility operations impact the effectiveness of DR strategies and identifying the best operation practices and behaviours to enhance the impact of DR activities.
- Investigating the use of distributed power generation technologies at wastewater facilities.

2.1.2 Energy Efficiency

Wastewater utilities are actively working to reduce the energy use of their facilities by increasing efficiency. Energy efficiency is part of the process to reduce energy demand along the path to a net energy neutral wastewater treatment plant. Briefly, wastewater treatment plants can target energy efficiency by replacing or improving their core equipment, through use of variable frequency devices (VFDs), appropriately sized impellers and implementation of energy-saving automation schemes. Efficiency can also be improved at the process level, by implementing low energy treatment alternatives to an activated sludge process or improving process control. Table 2.2 summarizes the energy efficiency opportunities in the wastewater sector.

Table 2.2 Opportunities for energy efficiency in wastewater treatment facilities

Examples of Energy Efficient Equipment, Processes and Technologies	
Equipment	▪ Premium efficiency motors alternating current (AC) motors ▪ Variable-Frequency Drives (VFDs) ▪ High efficiency blowers ▪ Energy efficient HVAC ▪ Energy smart lighting ▪ Energy submeters ▪ Advanced SCADA and control systems
Process/Technology	▪ Low energy treatment processes ▪ Improved wastewater screening ▪ Advanced SCADA, on-line sensors and automatic controls ▪ Fine bubble diffusers for aeration ▪ Automatic dissolved oxygen (DO) control ▪ Low energy odor control ▪ Light Emitting Diode (LED) Ultraviolet (UV) lamp disinfection ▪ System configuration (e.g., centralized vs. decentralized) ▪ Increased influent storage capacity

2.1.2.1 Energy Efficient Equipment

There are numerous types of energy efficient equipment that a wastewater utility can utilize to reduce energy consumption. Common facility-wide plant improvements include upgrade of electric motors and the installation of VFDs in pumps. These modifications can result in substantial energy efficiency because at least 60% of the electrical power fed to a typical wastewater treatment plant is consumed by electric motors (Spellman, 2013). VFDs enable pumps to accommodate fluctuating demand and allow more precise control of processes. VFDs can reduce a pump's energy use by up to 50% compared to a motor running at constant speed for the same period. Wastewater treatment facilities can also upgrade their heating, cooling, and ventilation systems (HVAC) to improve energy efficiency and reduce energy costs. The latest developments in HVAC equipment can substantially reduce cooling energy use by approximately 30 to 40% and achieve energy efficiency ratios as high as 11.5. The latest air-source heat pumps can reduce heating energy use by about 20 to 35%. Water-source heat pumps also have superior ratings, especially when outside air temperatures drop below 20 degrees Fahrenheit (°F) (15.2 energy efficiency ratio) and can use heat from treated effluent to supply space heating. The Sheboygan Wastewater Treatment Plant reduced its energy consumption by 20% from 2003 solely by implementing energy demand management strategies that targeted efficiency by equipment replacement (e.g., motors, VFDs, blowers, etc.) and scheduling of regular maintenance (Liner and Stacklin, 2013).

Wastewater treatment plants have also recently used advanced sensors and control devices to optimize energy so that what is supplied meets but does not exceed the actual demand. For example, the adoption of lower dissolved oxygen set-points in the aeration basin can still maintain microbial growth and generate energy savings of 15-20% (Kang et al., 2010). The installation of energy submeters is another important plant improvement that, however, can require high capital investments for a utility. Recent advances in lamps, luminaries, controls, and lighting design provide numerous advantages over traditional lighting systems. Since lighting accounts for 35 to 45% of the energy use of an office building, the installation of high-efficiency alternatives for nearly every plant can dramatically reduce the operational energy bill for the utility. Incentives and rebates are commonly available from electric utilities and other agencies, such as NYSERDA, to support the installation of energy-efficient fixtures and equipment that reduce energy use financial impacts (Leiby and Burke, 2011).

2.1.2.2 Energy Efficient Process and Technology

Wastewater treatment plants can target energy efficiency by implementing process and/or technologies that have lower energy demand. To date, many wastewater and some potable treatment technologies are biological and, in recent years, new molecular and microbiological techniques and processes that are more energy efficient have been developed and implemented at the full-scale level (Environmental KTN, 2008). In recent years, research based on novel biology has focused more attention on developing treatment systems with lower oxygen, thus energy, requirements for the removal of organic nitrogen and ammonia. Alternative treatments such as Single reactor system for High activity Ammonium Removal Over Nitrite (SHARON) (e.g., Rotterdam, Netherlands), ANaerobic AMMonium Oxidation (ANAMMOX) and DEamMONification (DEMON) (e.g., Strass, Austria) are very promising and should be considered for new designs or retrofits of existing plants. ANAMMOX bacteria, for example, are very slow growing, making their transition to full-scale systems difficult. Successful mainstream deammonification treatment processes must retain slow growing anammox bacteria in the system. Recent research suggests that anammox bacteria can form heavy granules that can be separated from the waste activated sludge, whereby the heavier Anammox-laden sludge can be retained and concentrated in the system. Side-stream treatment options using these treatment alternatives or ammonia recovery processes (e.g., at the 26th street treatment plant in New York City) have also been considered to reduce nutrient loadings at the wastewater treatment plant head (Kang et al., 2010). Although sidestream treatment has been used successfully overseas and has significantly reduced energy consumption, the use of such treatment processes (DEMON, ANAMMOX, and others) in North America has been limited. Recent development in bioengineering opens the opportunity for new innovative and efficient processes that need bench and pilot-testing before full-scale adoption (Environmental KTN, 2008).

Efficient control strategies have been accepted and proven to be successful for both feed-forward and feedback controls applied through supervisory control and data acquisition systems (SCADA) in many full scale applications. A wide variety of acceptable sensors are now available for dissolved oxygen, ammonia, nitrate, and oxidation-reduction potential (ORP). In a recent study funded by WERF, a guidebook was developed for an operational control method for optimizing lift station systems in wastewater treatment using advanced hydraulic modeling and new generation SCADA. This method of operation, piloted at JEA, was expected to reduce operating pressures in a common force main, reduce the energy demands (by approximately

15%) and costs of the pumping units, and stabilize the influent flow entering the water resource recovery facility, thus reducing the aeration requirements of the biological process (Wilcoxson and Badruzzaman, 2013).

Aeration is the largest energy user in a typical wastewater treatment plant, thus the aeration process should be evaluated when implementing energy reduction programs. Installing automatic dissolved oxygen control enables continuous oxygen level monitoring in the wastewater and so that aerators can be turned off when the oxygen demand is met. Based on the aeration capacity of the wastewater treatment system and the average wastewater oxygen requirement, the automated dissolved oxygen control can be the most cost effective method to optimize aeration energy and achieve energy savings up to 25% to 40% if compared to manually controlled systems. In addition to automated control systems, the installation of smaller modular and high efficiency blowers to replace centralized blowers, the proximity of the blowers to the aeration basin to reduce energy losses from friction, and the installation of high efficiency pulsed air mixers are important efficiency measure to be considered.

Fine pore diffusions have been widely introduced as a subsurface form of aeration, due to their aeration efficiency (mass of oxygen transferred per unit energy required) (Rosso et al., 2010a). One of the process parameters to increasing oxygen transfer efficiency is the mean cell retention time (MCRT), since higher MCRT systems remove or sorb the surfactants early in the process and improve removal of biodegradable organics. Simplified, automated off-gas monitoring instruments, operating in real-time mode and self-calibrating, can be used to measure oxygen transfer efficiency (OTE) for extended periods of operation, which helps to identify strategies for energy-conservation in municipal wastewater treatment plants (Rosso et al., 2010b).

About 10-40% of the total energy consumed by wastewater treatment plants is consumed for sludge handling. Most of the energy required is due to the shear force applied for dewatering, solids drying and treatment of high-strength centrate. As an example, in California centrifuge and belt filter presses consume 30,000 kWh/year/MGD and 2-6,000 kWh/year/MGD, respectively (Rajagopalan, 2014). Many studies have been conducted on understanding sludge dewatering processes and improving their efficiency. Recent studies by the Energy Commission have focused on the improvement of sludge dewatering to achieve lower energy consumption by using nanoparticulate additives. By implementing this solution at wastewater treatment plants in California, the state would be able to save an additional 10.5 million kWh per year, which includes the cost of energy, polymer and nanoadditives for sludge dewatering, and sludge disposal (Rajagopalan, 2014).

Another innovation directed toward more energy efficient systems is the use of distributed systems in place of the centralized treatment systems historically favored due to their economies of scale. Centralized plants are generally located down gradient in urban areas, permitting gravity wastewater flow to the treatment plant, while the demand for reclaimed wastewater generally lies up gradient. This means higher energy demands for pumping the reclaimed wastewater back to the areas in need. These energy costs can be reduced through use of smaller distributed treatment plants located directly in water limited areas (McCarty et al., 2011).

In recent years, a number of organizations have developed tools and conducted research to promote energy efficient best practices. However, estimates of energy efficiency and demand response potential in water and wastewater systems, associated economics and related guidelines are lacking. Supported by WERF, WRF, and other international research organizations, the Global Water Research Coalition (GWRC) coordinated the preparation of a compendium of global best practices which provided one of the largest sets of case studies on energy efficiency and production in the wastewater sector (Brandt et al., 2010), *Energy Efficiency in the Water Industry: A Compendium of Best Practices and Case Studies* (Brandt et al., 2010). WERF also compiled the energy savings achieved from energy efficiency measures in North America, *Energy Efficiency in Wastewater Treatment in North America: A Compendium of Best Practices and Case Studies of Novel Approaches* (Crawford and Sandino 2010), and NYSERDA sponsored the *Energy Efficiency in Municipal Wastewater Treatment Plants: Technology Assessment* (NYSERDA, 2004). The above mentioned research reports have highlighted the need for additional research on energy efficiency and low energy treatment alternatives. R&D opportunities in energy efficiency and low energy alternative processes are listed in the Research Opportunities for Energy Efficiency – Processes and Technologies section presented below.

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Energy Efficiency – Process and Technologies

Mainstream and Sidestream Treatment

- Determine the conditions under which an improved screening pre-treatment approach can be a feasible and financially attractive option to reduce energy demand in wastewater treatment processes.
- Determine the feasibility of alternative low-energy sidestream treatments (DEMON, Anammox, etc.), the facility conditions and related sludge separation processes in support of these processes for mainstream treatment, and their scale-up potential for mainstream biological nutrient removal facilities.
- Identify other anaerobic or innovative fixed film and membrane processes that also have potential to provide low energy treatment based on emerging research.
- Develop, model and trial novel treatment processes utilizing new microbial consortia ("designer bugs") (Environmental KTN, 2008).
- Develop and demonstrate benefits of new low energy fine bubble aeration technologies, high-speed gearless turbo-blowers for aeration and counter current systems for both activated sludge plant aeration and dissolved air floatation plants (Environmental KTN, 2008).
- Assess through demonstration: (1) the feasibility or performance of online respirometry and provide information on remote sensing options (Arzbaecher et al., 2013).
- Design for modularity. Assess the practical implications of modular design. (Environmental KTN, 2008).

Sludge Processing

- Provide a more perspicuous understanding of new technologies such as solar drying of sludge.
- Develop new drying techniques to reduce energy usage and transportation costs. Develop strategy through demonstration projects (Environmental KTN, 2008).
- Understand the relationship and interaction of nano-additives for enhanced sludge dewatering (Rajagopalan, 2014).
- Evaluation of the impact of nano additives for sludge dewatering on receiving waters and sources of drinking water.
- Develop low energy odor control (Environmental KTN, 2008).

Disinfection

- Evaluate novel photo-catalytic oxidation techniques to replace disinfection and other contaminant oxidation processes (e.g., endocrine disrupting compounds) (Environmental KTN, 2008).

2.1.3 Energy Recovery and Generation Opportunities

Several types of technologies and opportunities exist to recover energy from influents and biosolids (biogas) throughout wastewater treatment processes (Kang et al., 2010). Energy recovery strategies could help offset the electricity consumption of the wastewater sector (Stillwell et al., 2010). Some of these opportunities are well established; others are innovative technologies that will require additional research and development. By recovering and generating energy, wastewater treatment plants could potentially become energy self-sufficient. Typically, it is harder for wastewater plants in the United States to achieve total energy self-sufficiency than their European counterparts, since wastewater in the United States is typically more dilute, resulting in higher operational costs (e.g., pumping and aeration) per unit volume treated.

Table 2.3 highlights various energy recovery and generation opportunities in wastewater treatment plants and related processes, technologies or operational practices by which recovery and generation might be achieved. Processes and technologies already in use at wastewater treatment plants include biogas-powered combined heat and power (CHP), thermal conversion from biosolids, renewable energy sources (e.g., systems solar arrays and wind turbines), energy recovery at the head of the wastewater treatment plant and within the treatment process.

Energy recovery from anaerobic digestion with biogas utilization and biosolids incineration with electricity generation is widespread, but there is potential for further deployment. Of the approximately 837 biogas generating facilities in the United States, only 35% generate electricity from biogas and only 9% sell electricity back to the grid (Liner and Stacklin, 2013). The low application rate is partly due to the dominance of small wastewater systems in the United States (less than 5 MGD). It is estimated that anaerobic digestion could produce about 350 kWh of electricity for each million gallons of wastewater treated at the plant and save 628 to 4,940 million kWh annually in the United States (Stillwell et al., 2010). The electricity produced by CHPs is reliable and consistent, but the installation requires relatively high one-time capital costs. Research shows that recovery of biogas becomes cost-effective for wastewater treatment plants with treatment capacities of at least 5 MGD (Mo and Zhang, 2013; Stillwell et al., 2010). Various wastewater treatment plants, such as by the East Bay Municipal Utility District (Oakland, California) and the Strass WWTP (Austria) became a net-positive, energy-generating wastewater plant by powering low-emission gas turbines with biogas from co-digestion processes.

Recovery of carbon will enhance the efficiency of methane (biogas) generation and reduce sludge volumes. Methods to improve methane production efficiency, such as the transformation of refractory carbon into a bioavailable nutrient by WAS pre-treatment are directly linked to the energy recovery and generation opportunities. These pretreatment technologies have recently been introduced to improve the conversion of organic material and cell matter to biogas. Methods such as physical or electrical cell rupturing and high pressure steam injection or heating are well proven or being tested. Examples of these methods are: thermal hydrolysis (e.g., Cambi), sonication, BioThelys process, mechanical disintegration, electrical pulse treatment, homogenization, pressure release and mechanical shearing methods

(Jolly and Gillard, 2009). Some of these processes not only increase biogas yield but can be fully integrated and take advantage of the energy flow of the plant. These processes, in fact, need heat, electricity or biogas inputs to satisfy their energy requirements and in some cases, these requirements are fully satisfied within the plant. For example, thermal processes, such as thermophilic digestion and enhanced enzyme hydrolysis can be fully supported by CHP heat with no additional heat requirement. Whether investment in such technologies is beneficial to a utility typically depends upon the capital and operation and maintenance (O&M) costs of the equipment as well as the sludge disposal route (Jolly and Gillard, 2009).

Biosolids incineration with electricity generation is an effective energy recovery option that uses multiple hearth and fluidized bed furnaces. Fluidized bed furnaces are a newer and more efficient technology, stable, and easier to operate than multiple hearth furnaces, but are limited to continuous operation. Both incineration technologies require cleaning of exhaust gases to prevent emissions of odor, particulates, nitrogen oxides, acid gases, hydrocarbons, and heavy metals. As for biogas-generating electricity, incineration can be used to power a steam cycle power plant, thus producing electricity in medium to large wastewater treatment plants where a high amount of solids is produced. Disadvantages of incineration are high capital investments, high operating costs, difficult operations, and the need for air emissions control (Stillwell et al., 2010). Despite these disadvantages, biosolids incineration with electricity generation is an innovative approach to managing both water and energy. For example, the Hartford Water Pollution Control Facility in Hartford (Connecticut) is incorporating an energy recovery facility into their furnace upgrade project and they anticipate that biosolids incineration will generate 40% of the plant's annual electricity consumption (Stillwell et al., 2010).

Wastewater utilities can now strategically replace incineration with advanced energy recovery technologies (MWH Global, 2014). Like incineration, gasification and pyrolysis offer the potential to minimize the waste mass for ultimate disposal from processing sewage sludge for its sludge treatment centers and also offer the prospect of greater energy recovery and/or lower operating cost than that offered by incineration (MWH Global, 2014). The range of gasification technologies available is large and at present it is believed that there are further synergies, such as recovering heat for digester and/or thermal hydrolysis process heating, that can be derived for a digestion or advanced digestion/ gasification advanced energy recovery. Pyrolysis, offers further advantages over the gasification options due to the production of a better syngas product than gasification, favoring more effective gas engine/CHP power generation. For carbon footprint reduction, raw sludge pyrolysis or Advanced Energy Recovery (AER) technology paired with advanced anaerobic digestion provides the best outcomes (MWH Global, 2014).

Anaerobic treatment of domestic wastewater has the potential for capturing wastewater's organic energy content. Retrofitting existing conventional aerobic wastewater treatment plants to become complete anaerobic facilities could be costly and has not received as much study as the aerobic treatment technology. The complete anaerobic approach might best be applied with new treatment systems once sufficient experience is gained (McCarty et al., 2011).

Renewable energy sources have been used directly or indirectly in wastewater treatment. Solar energy, in stabilization ponds or solar detoxification, is often used for wastewater treatment. Heat recovery from sewer lines to power steam turbines is another emerging practice that is under demonstration in the Camden County Municipal Utilities Authority (New Jersey). These and other pioneering wastewater utilities are creating models that can be replicated in communities across the nation (The Johnson Foundation, 2013).

Recently, research has focused on potential resource recovery opportunities, strategies and technologies in wastewater treatment facilities. WERF has a new five-year research plan for energy production and efficiency with the goal of increasing the number of treatment plants that are net energy neutral and to establish renewable energy recovery from wastewater (Cooper et al., 2011). At the international level, the United Kingdom Water Industry Research (UKWIR investigated the potential for exploiting a Renewable Heat Incentive, a government economic incentive for energy opportunities from the wastewater industry, where for example, exporting surplus biomethane into the national gas grid (or as a vehicle fuel) or reuse heat from incineration plants, or conversion to hydrogen in fuel cells could be developed. Specific research opportunities identified from the above mentioned reports and from those of other agencies are listed in the Energy Recovery and Generation Research Opportunities section below.

Table 2.3 Energy recovery and generation opportunities in wastewater treatment facilities

Energy Recovery and Generation Opportunities	
Anaerobic Digestion of Biosolids	▪ Improved solids capture (e.g., reduce MCRT) ▪ Advanced Filtration ▪ WAS pre-treatment ▪ Co-digestion of organic waste with biosolids ▪ Innovative use of biogas ▪ Advanced Biogas cleaning
Thermal Conversion	▪ Biogas cleaning opportunities ▪ Incineration ▪ Pyrolysis (sludge to oil) ▪ Gasification (sludge to syngas) ▪ Carbonization (sludge to fuel) ▪ Supercritical water oxidation (Aquacritox) ▪ Steam reformation
Anaerobic Treatment	▪ Upflow Anaerobic Sludge Blanket (UASB) ▪ Anaerobic migrating blanket reactors
Combustion or Recovery of Nutrients	▪ Ammonia in sidestream wastewater burned used as a fuel source to produce electrical energy ▪ Nitrogen oxides capture as fuel enhancers ▪ Oxygen recovery from nitrate
Algae-based Systems	▪ Microalgae ▪ Algae bioreactors
Bioelectrochemical Systems	▪ Microbial fuel cells ▪ Microbial electrolysis cells
Alternative and Renewable Energy	▪ Small and micro-hydropower ▪ Solar ▪ Wind ▪ Geothermal ▪ Capture of raw wastewater heat at plant's head

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Energy Recovery and Generation

General

- Improve/innovate technologies that have low capital costs, are simple and affordable to operate, and are easy to integrate into the existing small plants with flows < 1-5 MGD. Develop best practice guidelines for small utilities.
- Study life cycle environmental impacts that are lacking for most of the onsite energy generation technologies.

Anaerobic Digestion and Biogas Production

- Promote research to identify less-costly methods to achieve anaerobic digestion and biogas production so it can become more widely applicable, particularly to small WWTPs and for industrial applications.
- Assemble information on the barriers to anaerobic digestion and further advance understanding of how decision science and innovation diffusion theory can help overcome barriers to biogas use for renewable energy at wastewater treatment utilities (Willis et al., 2012).
- Develop a centralized database of CHP installations and continue to develop case studies on successful CHP projects (Willis et al., 2012).
- Develop an economic analysis tool that uses other financial evaluation methods in addition to simple payback and identify how to pursue legislation to assist in financing CHP projects (Willis et al., 2012).
- Develop an education and training course to assist in the understanding the benefits of biogas, including a course specifically for decision makers (Willis et al., 2012).
- Support the WEF renewable energy statement to move biogas to the DOE list of renewable energies (Willis et al., 2012).
- Evaluate biogas clean–up opportunities (ACEEE, 2005).
- Develop industry standards, protocols and successful business models for advanced biogas development programs and net zero facilities at wastewater treatment plants.
- Identify business practices that maximize renewable energy production potential through implementation of co-digestion and increased performance of anaerobic digestion to maximize generation of gases. These studies could also investigate how to reduce the costs associated with gas emissions and clean-up (AWE and ACEEE, 2013).
- Develop and undertake large scale trials of new process flowsheets for wastewater treatment using anaerobic treatment (Environmental KTN, 2008).

Sludge Pre-Treatment

- Investigate and promote demonstration studies of WAS pre-treatment alternatives and of digesters enhancement to increase biogas yield during anaerobic digestion (Arzbaecher et

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Energy Recovery and Generation

Thermal Treatment

- Further research into waste heat recovery for power generation from incineration being used for waste volume minimization.
- Further investigate supercritical water oxidation, pyrolysis and gasification for sludge destruction (Environmental KTN, 2008).
- Study the maximum amount of energy that can be generated onsite by integrating energy recovery from biogas with biosolids incineration.

Sludge Handling

- Develop strategies to address Class A sludge (ACEEE, 2005).

Renewable Energy

- Further enhance and assess the use of renewable energy in water/wastewater treatment system (ACEEE, 2005).
- Examine the integration and tradeoffs of onsite energy generation technologies. For instance, wind and solar technology and effluent hydropower technology can be integrated with other technologies without compensating the generation potentials of those technologies.
- Develop industry standards, technologies, protocols and business models for the development of renewable energy solutions at wastewater utilities and facilitate compliance with regulatory and environmental requirements, such as advanced biogas development programs (gas clean-up and emissions controls) and net zero facilities (AWE and ACEEE, 2013).

New Technologies

- Further exploration of the biological conversion of methane in biogas into methanol-based biofuel.
- Develop and or trial novel intensive and integrated processes using micro-fluidics, novel filtration and membranes, such as MBRs (Environmental KTN, 2008).
- Consider microalgae oxygenation in place of conventional aeration (ACEEE, 2005).
- Investigate the use of "super-bug" or other no-sludge technologies in wastewater treatment processes (ACEEE, 2005).
- Study microbial fuel cells and microbial electrolysis cells to advance the technology to the commercial scale.

2.1.4 Resource Recovery

2.1.4.1 Nutrient Recovery

Nutrient recovery from wastewater can offset the environmental loads associated with producing the equivalent amount of fertilizers from fossil fuels (Mo and Zhang, 2013). Various nutrient recovery methods have been applied in wastewater treatment processes and include biosolids land application, urine separation, controlled struvite crystallization and nutrient recovery through aqua-species. Biosolids land application involves spreading biosolids on the soil surface or incorporating or injecting biosolids into the soil. Urine separation involves separation of urine from other wastewater sources for recovery of nutrients. The process is promising in terms of maximizing nutrient recovery from wastewater, because around 70-80% of nitrogen and 50% of phosphorus in domestic wastewater is contained in urine (Maurer et al., 2003). Controlled struvite extraction processes have high nutrient recovery potential because of their high concentrations of phosphorus, ammonium and magnesium (Forrest et al., 2008). Although not widely applied, aqua-species, such as macroalgae, microalgae, duckweed, crops and wetland plants after utilizing nutrients in wastewater, can be harvested and used as fertilizers or animal feeds (El-Shafai et al., 2007).

While these individual resource recovery methods have been studied, there is a paucity of peer-reviewed articles focusing on the current status and sustainability of these individual methods as well as their integration at different scales (Mo and Zhang, 2013). Recently, a few research programs have started investigating the potential for nutrient recovery, including carbon, nitrogen and phosphorus from wastewater treatment process. A recent report from WERF with support from the Commonwealth Scientific and Industrial Research Organization (CSIRO), *Resource Recovery from Wastewater: A Research Agenda,* summarized and defined the future research needs for the resource recovery opportunities in the wastewater sector (Burn et al., 2014).

WERF is developing a tool for the implementation and acceptance of resource recovery technologies at WWTPs, with a major focus on extractive nutrient (phosphorus) recovery technologies that employ greater energy efficiency and offer monetary savings (Latimer, 2014). WERF has prioritized high profile research on P concentration and recovery opportunities during wastewater treatment processes. Polyphosphate-accumulating organisms (PAO) can be responsible for P concentration in cells and direct concentration and precipitation of struvite that can be recovered for niche agricultural markets (Burn et al., 2014). This report implies that nitrogen recovery seems to be a lower priority than carbon (through biogas) or phosphorus recovery, unless combined with other recovery opportunities. N recovery is possible through the use of adsorption/ion-exchange, precipitation and stripping processes. A $26 million ion-exchange pilot facility in New York that concentrated ammonia from recycle streams (centrate) of anaerobically digested sludge showed that the above mentioned methods are viable, however not yet as cost effective as the Haber-Bosch process (Burn et al., 2014).

R&D opportunities in the integrated nutrient recovery options have been highlighted in various reports and are listed below.

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Nutrient Recovery

- Perform life cycle studies for nutrient recycling technologies, especially for urine separation, controlled struvite precipitation and nutrient recovery through aqua-species.
- Develop a consistent framework for comparing the processes and end-uses of their biosolids. So far, life cycle studies on land application of biosolids has been carried out in different regions, evaluated by different impact categories and based on different cases and different biosolids management methods.
- Investigate the integration of these nutrient recycling technologies, such as upstream urine separation with downstream constructed wetlands since urine separation does not remove all the nutrients in the wastewater.
- Understand the tradeoffs between different technologies when they are integrated in the WWTP process and the appropriate scale for implementing the technologies (community level or municipal level). Studies are also needed to investigate the maximum recovery potential under integrated nutrient recycling.
- Investigate life cycle energy benefits associated with reducing and reusing organic and nutrient loadings from wastewater and waste volume for downstream handling. Energy generation potentials have been reported for most of the onsite energy technologies, but these studies have focused on direct energy generation.
- Understand nutrient availability from biosolids relative to inorganic fertilizers; alternatives to aluminium sulphate (alum) and ferric coagulants need to be identified as the use of these chemical coagulants results in decreased fertilizer quality of the resultant biosolids (Burn et al., 2014).
- Perform demonstration projects and proof of concept to utilize thermal treatments, such as pyrolysis, to treat this reduced sludge stream and simultaneously produce biochar and biogas (Burn et al., 2014).
- Understand and develop markets for by-products to promote resource recovery and off-set set-up costs and the development of alliances and partnerships between different stakeholders is also crucial (Burn et al., 2014).

2.1.4.2 Water Reuse

Treated wastewater can be reused for various beneficial purposes to provide ecological benefits, reduce the demand of potable water and augment water supplies (Mo and Zhang, 2013). Beneficial uses include agricultural and landscape irrigation, toilet flushing, groundwater replenishing and industrial processes (EPA, 2004). Currently, around 1.7 billion gallons per day of wastewater is reused in the US, and this reuse rate is growing by 15% every year (Mo and Zhang, 2013) and Florida and California are pioneering states in the country focusing on water reuse. The level of wastewater treatment required varies depending on the regulatory standards, the technologies used and the water quality characteristics. Some of the treatment process or schemes utilized are able to save energy for the same amount of water delivered.

Recently WERF and the WateReuse Research Foundation funded various studies that looked at Low Energy Treatment Schemes for Water Reuse (Bollaci, 2013). One of the studies used Biowin modeling simulations to evaluate operating conditions and treatment levels of water reuse processes that could improve effluent quality and reduce energy use (Nikkel et al., 2013). The treatment scheme studied was composed of forward osmosis (FO), membrane distillation, anaerobic membrane bioreactor, SHARON/ANAMMOX and struvite precipitation. The use of minimal aeration processes (FO) and the possibility of recovering valuable compounds, such as struvite and methane, reduce energy consumption and operating costs (Salveson, 2013). A second study used simple mathematical modeling to compare conventional activated sludge systems with Membrane Aerated Biofilms Reactors (MABR) that can achieve 100% oxygen transfer efficiency and save up to 85% of electrical energy compared with conventional activated sludge systems (CAS). Parameters that affect the performance of the MABR processes include design flux for chemical oxygen demand (COD) and total nitrogen (TN), membrane, mixing energy requirements, lifetime of membrane, etc. (Nerenberg et al., 2013). Two other studies evaluated an Anaerobic Membrane Bioreactor (AnMBR) operating at a psychrophilic temperature as a low energy process alternative by employing a laboratory demonstration and a Life Cycle Energy Methodology. The process has the potential to become energy positive, through improvement of methane recovery, use of more energy efficient membrane scouring and achievement of higher flux rates (Salveson, 2013; Skerlos et al., 2013).

R&D opportunities associated with water reuse options at wastewater treatment facilities have been highlighted in various reports and are listed below.

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE
Water Reuse

- Perform pilot and demonstration studies to ensure compatibility of low energy treatment processes with conventional process trains, evaluate their capital and operating costs, and evaluate the ability to retrofit existing treatment systems.
- Identify MABR configurations to achieve N and P removal and better quantify the variables that impact MABR processes and develop/test scalable and retrofittable reactor configurations.
- Investigate the optimization of MABR operating conditions, such as the SOTE correction factors, gas transfer in MABR (often limited by back-diffusion), the dissolved methane release of AnMBR to the environment and technologies for recovery.
- Investigate the potential to use novel low-energy downstream treatment technologies that utilize the dissolved methane for nutrient removal and advancement in methane capture or downstream conversion of soluble methane from AnMBR.

2.1.4.3 Integrated Resource Recovery

Onsite energy generation, nutrient recycling and water reuse can be integrated within WWTPs to achieve maximal resource recovery (Mo and Zhang, 2013). An integrated resource recovery plan achieves the reduction of both material uses in the WWTPs and of energy consumption. Resource recovery technologies are available but options need to be holistically investigated and understood to achieve maximal benefits from recovery within the context of sustainability objectives since tradeoffs among various resource recovery methods exist (Mo and Zhang, 2013; Liner and Stacklin, 2013). When more resources are recovered in a wastewater process, the amount of energy available for generation decreases and higher energy consumption is often observed (Liner and Stacklin, 2013). For instance, when more waste organic matter is converted to biogas-energy, nitrogen is mostly lost as ammonia in the gas phase or in the supernatant from centrifuged anaerobically digested sludge. Thus, less nitrogen is retained in the biosolids and not recoverable through land application. Another example is in the installation of heat pump systems, which is beneficial when the demand is located close to the WWTP; in contrast, onsite wind energy generation systems might be better located away from the local residents (Verstraete et al., 2009).

Although there is integrated resource recovery in practice currently, particularly at the community level, the related studies are rare. In a WWTP in Florida onsite energy generation, nutrient recycling and water reuse are combined: CHP is used to generate electricity from the digested gases, biosolids are sold for land application and part of the treated water is used for agricultural and landscape irrigation. In general, to date, very limited studies have reviewed the integrated energy-nutrient-water recovery in WWTPs, particularly on a national-scale (McCarty et al., 2011; Mo and Zhang, 2013; Verstraete et al., 2009) and there are no studies optimizing the resource recovery via multiple approaches (Mo and Zhang, 2013). R&D needs and opportunities for integrated resource recovery options have been highlighted in various reports and are listed below.

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Integrated Resources Recovery

- Evaluation of integrated design combining onsite energy generation, nutrient recycling, and water reuse needs in terms of economic and environmental aspects (e.g., carbon footprint) before implementation.
- Research and practices on integrated resource recovery in WWTPs need to be encouraged on a national scale, through funding, policy instruments, and regulations (Mo and Zhang, 2013).

2.2 Energy Management Opportunities in Drinking Water and Desalination

Water utilities have become increasingly energy intensive and responsible for approximately 1-3% of annual electricity consumption in the United States (Boulos and Bros, 2010; EPA, 2012b; Sanders and Webber, 2012; Arzbaecher et al., 2013). Future projections estimate this percentage to double to 6% due to higher water demand and more energy intensive treatment processes (Chaudhry and Shrier, 2010). Estimates indicate that approximately 90% of the electricity purchased by water utilities, or approximately $10 billion per year, is required for pumping water through the various stages of extraction, treatment, and final distribution to consumers (Bunn, 2011; Skeens et al., 2009). Despite recent energy efficiency progress in pumping systems, there has not been any notable impact on existing energy intensity values. Furthermore, the energy use in drinking water utilities, with the exclusion of energy use for water heating by residential and commercial users, contributes significantly to an increasing carbon footprint with an estimated 45 million tons of greenhouse gases (GHG) emitted annually in the UnitedStates. (Griffiths-Sattenspiel and Wilson, 2009; Wallis et al., 2008).

In some cases, reduced energy use is intrinsic to the water system features or configuration. For example, New York's largest drinking water supply system consumes nearly 70 percent less energy (580 kWh/MG) than the national average (1,400 kWh/MG), by having many facilities that incorporate gravity distribution systems for at least a portion of the same service area and, thus, significantly reducing energy consumption and costs attributed to pumping (Yonkin et al., 2008).

In California, agricultural groundwater and surface water pumping is responsible for approximately 60% of the total peak day electrical demand related to water supply, particularly the energy consumed within Pacific Gas and Electric's (PG&E) controlled area. Over 500 megawatts (MW) of electrical demand for water agencies in California is used for providing water and sewer services to customers (House, 2007). The water related electrical consumption for the State of California is approximately 52,000 gigawatt hours (GWh) (House, 2007). Electricity use for pumping is approximately 20,278 GWh, which is the 8% of the state's total electricity use. The remaining is consumed at the customer end side for heat, pressurize move and cool water.

To address the challenges associated with poorer quality sources and/or reduced supply, water utilities have been exploiting new water supply options such as seawater and saline groundwater, the use of which is growing about 10% each year. The use of these new water sources require two to ten times more energy per unit of water treated than traditional water treatment technologies. For this purpose, more energy-intensive advanced treatment processes, such as membrane treatment for desalination, has been recently implemented but conventional, low-energy, treatment technologies still predominate in the water treatment industry. Ozone, for example, has not had a significant impact on overall energy intensity, due to rather low rates of implementation within the industry (Arzbaecher et al., 2013).

In the past, most of the research on energy management has focused on energy efficiency, recovery and generation opportunities, and related economics for primary energy associated with water treatment. Little attention has been given to secondary energy uses for source pumping, transport and distribution. The partnership project with EPR I and the WRF (Arzbaecher et al., 2013), provides updated information on the energy use and management by water utilities in the U.S and it also identifies opportunities for demonstration projects related to energy efficiency, demand response and new electrotechnologies.

Further details on the different energy management programs, strategies, technologies and related research and development needs are highlighted in the following sections.

2.2.1 Energy Load Management Strategies

Water utilities can control costs and manage their energy savings by implementing energy load management programs that take advantage of incentives and rebates from energy providers and shifting power consumption from electricity on-peak to off-peak hours and by adding a more effective use of storage. The Energy Commission identified various areas and research opportunities where the water sector can reduce its electric peak demand (House, 2007), such as improving the use of existing storage facilities and identifying new storage opportunities to take advantage of pumping at lower heads and additional pressure supply to the system.

Partnerships with energy providers may be particularly useful in identifying energy conserving options, such as in evaluating the schedule and timing of pump usage that can lead to significant cost reductions (although perhaps not energy use reductions) (Leiby and Burke, 2011). Recently, DR programs have been developed by electric utilities to promote an adequate supply and efficient distribution of electricity to end–users while providing incentives for reducing peak demand (PLMA, 2002). In addition, DR programs balance supply and demand in real–time, which helps overcome the uncertainties of intermittent electricity generation, particularly when provided by sources, such as wind energy, that are unpredictable (Kärkkäinen and Ikäheimo, 2009). The participation of customers inDR programs, such as time-of-use (TOU), by shifting their water demand to off-peak periods and the reduction of on-peak electrical demand, will result in large electrical energy savings for water agencies (House, 2007; House, 2011). For example, by shifting their water use to off-peak periods, the Coachella Valley Water District could reduce its peak electrical demand by 1,340 MWh and 3 MW (House, 2011).

In order to minimize operation and maintenance costs through load shifting and to integrate proper controls, installation of an energy management and water quality management system must be considered. In the early 1990s, the concept of *Energy and Water Quality Management Systems* (EWQMS) for drinking water distribution systems was developed by the AWWA Research Foundation (now WRF), in collaboration with EPRI. The implementation of EWQMS has increased in recent years, and today approximately twenty drinking water utilities have installed a commercial or in-house optimization tool at their facility (Jentgen et al., 2003; Cherchi et al., 2015). An EWQMS is a series of individual application software programs providing water utility staff with the data and tools to optimize the operation of the entire water system taking advantage of TOU tariff systems, and achieve high energy cost reductions.

EWQMS also provides for improved water quality and water supply management through ability to properly plan and schedule operations in view of changes in water demand, tariff structures or infrastructure modifications (Cherchi et al., 2015). A WRF/Energy Commission partnership project is developing and piloting an additional module of the EWQMS framework that will reduce greenhouse gas emissions while maintaining or increasing the current level of energy efficiency at drinking water facilities (Badruzzaman et al., 2015).

While previous studies have focused on energy requirements for water utilities, there is a lack of studies that estimate peak electric demand and peak use in the water sector (House, 2007). This lack of understanding of peak electrical demand and use is even more limited by the lack of water demand profiles that can be compared to electric use profiles in the water sector. Development of water demand profiles is very difficult and not monitored as well as electric use, due to the fact that water is billed by volume and not by time-of-use (House, 2007). Pricing water in a TOU structure is still a complicated task for water utilities, however it has the potential to offer large energy savings.

In many cases, successful water efficiency programs reduce the total revenues for water agencies under typical rate structures. However, in the energy sector, investments in supply programs, even conservation and efficiency related supplies, no longer result in reduced revenues in many states. Research is needed to investigate the potential for decoupling investments from revenues in water markets and other financial methods that would make conservation and efficiency programs more attractive and encourage alternative energy supplies. Better valuing of the different qualities and sources of water would also facilitate better choices of water resource applications that take the real cost/value of the supply and quality into consideration.

Some reports highlight the importance to develop rate structures, pricing constructs or financing mechanisms that eliminate the financial disincentives of water efficiency programs and more properly fund sustainable development and management strategies (AWE and ACEEE, 2013).

Research opportunities associated with electrical load management at water treatment facilities have been highlighted in various reports and presented below.

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE
Electrical Load Management

- Investigate the application of more efficient pumps, pump optimization and pump scheduling technologies, network management and low friction pipe linings (Environmental KTN, 2008).
- Conduct a comprehensive energy efficiency and demand response potential study focused specifically on the water and wastewater industries as a follow on to EPRI's 2009 study (Wilcoxson and Badruzzaman, 2013).
- Estimate peak electrical demand and peak use (kW) in the water sector and evaluate water demand profiles that can be compared to electric use profiles in the water sector (House, 2007).
- Identify the impact and response potential of additional water storage on on-peak demand reduction, operational electric bills, and evaluate what proportion of storage can be dedicated to electric demand response as opposed to water use (House, 2007).
- Assess the availability and cost of self-generation options available to water agencies (House, 2007).
- Estimate energy efficiency and demand response potential in water supply and drinking water systems, associated economics and related guidelines are lacking (AWE and ACEEE, 2013).
- Understand the implications, in terms of benefits and drawbacks, of TOU pricing versus volumetric tariffs for water use by integrating TOU water meters and determining TOU tariffs for customers (House, 2007).
- Further investigate water use profiles at the customer side, particularly for commercial industrial sectors that may not follow residential water use patterns (House, 2007).
- Investigate the potential for decoupling investments from revenues in U.S. water markets and other financial methods that would make conservation and efficiency programs more sustainable and encourage supply switching. Better valuing of the different qualities and sources of water would also facilitate better choices of water resource applications that take the real cost/value of the supply and quality into consideration.

2.2.2 Energy Recovery and Generation Opportunities

Drinking water utilities have opportunities for recovering and generating energy on-site, however, unlike wastewater facilities, these options are somewhat limited (Leiby and Burke, 2011). Typical renewable source options are like those applied in wastewater facilities, and previously listed in Table 2.2, and may permit reduced reliance on non-renewable energy derived from fossil fuels, and reduce carbon footprint (Lisk et al., 2013). In addition to the traditional, solar, wind, and hydropower projects, water utilities are beginning to explore other alternatives that have potential to generate energy by retrofitting water collection and delivery conduits with in-line hydro turbines. The most common approach is the use of in-line turbines that generate energy to run ancillary equipment such as pumps at the site location, such those installed at Portland Water Bureau. An ongoing work by the WRF focuses on the operational issues and risk mitigation of energy recovery opportunities from pressure reducing valve stations by in-line hydrokinetic turbines (Knapp and MacDonald, forthcoming).

Implementation of clean energy options have been particularly achieved in large water utilities, but from an economic standpoint may still not be cost effective for smaller utilities. Some larger water utilities have incorporated alternative energy sources having a great impact in shaping the market for clean electricity generation and supply. Solar, implemented at the City of Raleigh and Metropolitan Water District of Southern California, and wind installed at Inland Empire Utilities Agency water recycling plant, are among those clean alternatives that have been considered for implementation by large utilities with available land areas and exposed surface (Lisk et al., 2013). Tidal and wave energy harvesting is relatively young compared to other renewable options for water utilities. The use of these potential energy sources is limited to those facilities with access to the ocean.

Implementation of a renewable energy project is influenced by a number of factors intrinsic to the water utility geography, financial, and regulatory aspects. The WRF project by Lisk et al., 2013, presents data, opportunities, barriers, risks, costs, and benefits on a variety of renewable energy options available for water utilities seeking to diversify their energy supply portfolio. A project checklist for implementation of renewable energy at water utilities has been provided by the same study to help utilities understand the main steps to implement a successful project (Lisk et al., 2013). Acquiring off-site renewable energy from a supplier other than the local utility can be a complicated, and even costly, process if the energy consumers are not familiar with energy sales and markets.

Many funding and grant opportunities are available to water utilities from private agencies and government, as well as power purchase agreements with third-party energy service companies to help minimize or avoid upfront capital costs (Lisk et al., 2013). In 2014, twenty-nine states in U.S. had renewable energy portfolio standards (RPS) that allowed water utilities to generate credits for their electricity provider. Approximately 19% of New York's energy currently comes from large hydroelectric generation; 1% comes from other renewable energy mix, and the remaining 5% still needs to be achieved with wind, solar, biomass, fuel-cell, geothermal, and tidal renewable options. The state of California has an Efficiency and Renewables Division that is part of the Energy Commission that provides market-based incentives for new and existing utility-scale facilities powered by renewable energy and offers consumer rebates for installing new wind and solar energy generation systems. An active engagement between the water and electric power sectors may be able to influence future policy decisions that create mutually beneficial opportunities. At the federal level, the DOE is working on identifying strategic policies and research and development opportunities to encourage renewable and clean energy options at water and wastewater utilities.

Obstacles and barriers to the implementation of renewable energy projects at water utilities are typically related to the availability of funds, potential changes in the electric rates applied to the water utilities, the complexity of the energy supply transaction, and the approval from the power utilities (Lisk et al., 2013). In some cases, power companies have disincentives for water utilities seeking to implement renewable energy on-site, such as using higher electricity rates to cover for the reduction in electricity purchased. In other cases, climatic and/or geologic conditions may limit what technologies may be used. To overcome these barriers, many water utilities have directly purchased and operated equipment and/or leased space on-site to third-party renewable energy companies, through power purchase agreements, or purchasing offsets from third parties off-site to account for power use in high-energy applications such as desalination.

2.2.3 Energy Efficiency

Estimates indicate that between 10 and 30 percent cost savings are readily achievable by almost all utilities implementing energy efficient programs or strategies (Leiby and Burke, 2011). In addition to cost savings, improving efficiency will result in a number of benefits, including the potential to reinvest in new infrastructure or programs, reduce the pressure on the electrical grid, achieve environmental benefits and long-term sustainability goals, such as GHG emission reduction, and meeting federal and local regulations (Leiby and Burke, 2011). Implementing energy efficiency programs at utilities may not require important capital investments; however it may involve managing risks and tradeoffs that impact water quality and public health protection (Leiby and Burke, 2011). Water utilities have to confirm that energy efficiency improvements will not have adverse impacts on their consumers for these changes to be successful. As mentioned in previous sections, energy efficiency improvements can be made by utilities of all sizes and through optimization of existing assets and operations by introducing more efficient equipment/technologies or through process optimization. Details on these two practices are reported in the following paragraphs.

2.2.3.1 Energy Efficient Equipment

Energy savings for water utilities can be realized through a range of actions that target pumps and motors by installing premium efficiency motors and VFDs, properly resizing and maintaining pumping systems, and by implementing building upgrades (e.g., lighting and heating and cooling) or reducing system leaks etc. (Leiby and Burke, 2011). For example, Senon and colleagues (forthcoming) developed a guidance manual that helps drinking water pump station designers to minimize energy consumption and costs by improving pump wire-to-water efficiency, performing periodic pump efficiency testing, and understanding the appropriate application of variable speed drives.

Energy efficient processes and new technologies to be applied in the water treatment and desalination sector are still at the research stage or are under-development. For example, NeoTech Aqua Solutions, Inc. has developed a new ultraviolet (UV) disinfection technology (D438) that uses 1/10 of the energy compared to lamps required in similar flow conventional UV systems. The technology demands less electricity and results in a smaller electrical bill, less maintenance, and a smaller overall carbon footprint. An ongoing WRF project #4568 "Evaluation of Innovative Reflectance Based UV for Enhanced Disinfection and Advanced

Oxidation" will evaluate the NeoTech reflectance based UV technology to determine the reliability and effectiveness of the inactivation of microorganisms, the maintenance requirements, and the costs of operation and maintenance.

Estimates of energy efficiency in water supply and drinking water systems, associated economics and related guidelines are lacking. In recognition of the need to better document and share information on energy efficiency practices in the water sector, various organizations have recently issued a number of reports to provide compendia and guidance to water utilities on energy efficient best practices and potential of process or technological improvement. WRF and NYSERDA co-funded *Energy Efficiency Best Practices for North American Drinking Water Utilities*, which provides a searchable database of energy efficiency best practices with descriptions of 16 case studies and lessons learned. Other studies from the WRF have looked into energy efficiency for water utilities and have identified the promising developments and future opportunities from the adoption of novel (but proven at full scale) technologies (Brandt et al., 2010).

2.2.3.2 Energy Efficient Operations and Processes

Energy efficiency can be targeted in water supply and distribution system operations as well as water treatment. Efficient pump scheduling and network optimization are significant contributors to efficiency practices (Leiby and Burke, 2011; Senon et al., forthcoming; Badruzzaman et al., 2015). In order to ensure energy efficiency of a pump station, a comprehensive understanding of the system requirements is important. In addition, it is important to tailor the pumps to the system operating requirements to ensure that the Best Efficiency Point (BEP) is located close to the point of the system curve where the pump operates most often. A recent study covering 150 water pump tests (sizes ranged from 30 to 4,000 hp) in eight municipal water supply and distribution systems demonstrated that the average efficiency gap (i.e., the difference between the manufacturer's original best efficiency point and actual point of operation in the field) is around 12.7% and that average efficiency loss (i.e., the difference between the manufacturer's original BEP and the tested BEP) is 9.3% (Papa et al., 2013).

Optimization systems, such as EWQMS, are able to operate pumping systems more efficiently than simple level or pressure controls by selecting a pump or a combination of pumps that will supply the water demanded at the lowest specific energy (e.g., lowest kWh per MG) (Badruzzaman et al., 2015). Where variable speed drives are available, the software is able to select and operate pumps close to their BEP at minimum to maximum flow conditions on a real–time basis. Historically, pumps have been scheduled based on the "maximum flow" (i.e., run the pump until it can no longer handle the system requirement) or based on the "percent of maximum speed" (i.e., select a percent of the maximum speed and select the combination of pumps based on that criteria). However, none of these traditional methods provide an accurate estimation of the operational efficiency of the pumping system. In applications where multiple pumps are arranged in parallel operating in a lead–lag sequence, the specific energy (energy consumed per unit volume of water pumped as expressed in kWh/MG or kilowatt hours per 1,000 gallons [kWh/kGAL]) is used in the EWQMS to determine the most energy efficient control timing to start or stop a lag pump. Therefore, the combination of pumps is selected in a manner that minimizes the specific energy consumption of the entire station within operational constraints (Badruzzaman et al., 2015).

A significant percentage of energy input to a water distribution system is lost in pipes due to friction, pressure and flow control valves, and consumer taps (Innovyze, 2013). Network modifications and changes in operating rules may be combined with water resource and treatment management planning to provide a holistic source–to–tap assessment. In general, water network optimization practices vary according to utility needs, and changes made for energy management purposes always need to comply with water quality, flexibility and security objectives; thus, risk management plays a role in ensuring a balance between energy optimization and operational flexibility (Badruzzaman et al., 2015). Various metrics can be used to assess water network energy efficiency, including the evaluation of kWh/MG supplied (or grams of carbon dioxide per million gallons [gCO_2/MG]), the proportion of input energy utilized in pumping (wire–to–water efficiency) and transport (friction, tap and discrete energy losses) and, more broadly, the comparison of the minimum theoretical energy required with actual system performance (Hernández et al., 2010; Boulos and Bros, 2010). An understanding of the energy input and the spatial utilization of energy in water supply systems is required for water network optimization and accounting of associated energy savings. In general, only the operating areas with the greatest potential for savings are subject to optimization.

In water treatment, optimizing energy use focuses on ways to operate efficiently and reduce energy consumption. In a report by the WRF, a summary of energy consumption for different advanced treatment technologies was provided based on the data collected by the project case studies (Chang et al., 2008). The study identified the factors affecting these energy consumptions and the optimization operations that were needed to achieve low energy consumption for individual unit operations (Table 2.4). The results of this study show that UV and ozone have the lowest specific energy consumption compared to the other processes analyzed and that, in general, there is a potential that each process can be optimized to operate near the design capacity (Chang et al., 2008).

R&D opportunities for energy efficiency in water supply, distribution, and treatment have been highlighted in various reports and are listed below.

Table 2.4 Energy consumption for different advanced treatment technologies in selected case studies and related strategies to optimize energy efficiency

Treatment	Specific Energy Consumption (kWh/kGAL)	Factors Affecting Energy Consumption	Energy Efficiency Optimization
UV Disinfection ***Medium Pressure Lamp Systems***	0.02-0.09	Specific energy consumption decreases with increasing flow rate and total number of operating reactors	Operate at or near flow capacity
Ozone Disinfection ***LOX feed, VPSA feed, Ambient Air feed***	0.02-0.16	Ozone concentration affects all ozone systems (LOX, VPSA and ambient air)	Operate at or near design zone
Micro and Ultra-Filtration ***Pumps, Air scour, cleaning system***	0.4-1	Production rate and pre-treatment affect specific energy consumption. Coagulation and flocculation reduces specific energy consumption related to pumping. Addition of PAC increases energy consumption.	Reconfigure re-circulating lines and other operational improvements
Reverse Osmosis ***Feed Pumps***	0.5-4.8	Specific energy consumption increases linearly with feed pressure	Pre-blending, improved pump operating efficiency, new membrane materials and energy recovery systems
Membrane Bioreactors ***Pumps, Blowers***	3.0-7.5	Air Scour blowers represent ~40% of total specific energy consumption. Permeate pumps and aeration blowers account for 3-5%. Specific energy consumption for permeate pumps depends on membrane pore size.	Minimize the frequency of air scour
Electrodialysis Reversal ***Electrified Membrane Plates***	4.3	Fixed energy consumption (building, HVAC, mixers,) is considered small relative to electrical dialysis reversal (EDR). More data needed to determine the effect of TDS or other parameters.	Although insufficient data available, improved efficiency potentially could be achieved by operating near design recovery

Adapted from Chang et al., 2008

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Energy Efficiency

- Estimate energy efficiency in water supply and drinking water systems, associated economics and related guidelines (AWE and ACEEE, 2013).
- Development and demonstration of new membranes of new materials such as biomimetics, nanocomposites and nanotubes; forward osmosis and dual reverse osmosis with chemical precipitation, capacitive deionization, ion concentration polarization, and dew-vaporation (Arzbaecher et al., 2013).
- Develop an accessible easy-to-use searchable database maintained and updated over time as example guidance for other water utilities seeking to learning more about these energy efficiency programs to reflect the new tools and resources that are published on a frequent basis (Leiby and Burke, 2011).
- Development of ultraviolet light emitting diodes (UV LED) for disinfection (NYSERDA, 2008b).
- Assess the impact of membrane characteristics (thickness and hydrophobicity) on pumping requirements for MBR systems, frequency and duration of air scour cycles in MBR and on energy efficiency of a given system (Chang et al., 2008).
- Determine how biofouling can be reduced to optimize energy consumption (Chang et al., 2008).
- Assess temperature ranges that have the greatest influence on RO systems and possible mitigation measures for improving energy efficiency (Chang et al., 2008).

2.2.4 Energy Management Opportunities in Desalination

Desalination provides an important supplemental source of drinking water that utilizes either thermal or membrane processes developed over the past 40 years. Though desalination accounts for a small percentage of worldwide water production, global and domestic implementation of desalination technology has risen dramatically in the last 20 years. In certain regions, these technologies play a significant part in water supply and treatment. Southern California, for example, includes 16 reclamation facilities, eight desalination facilities, 26 brackish water facilities, five municipal water treatment facilities serving more than 500 people, and 18 small municipal water treatment facilities serving less than 500 people, all utilizing RO membrane filtration systems and a number performing micro- and ultra-filtration (Rosso and Rajagopalan, 2013).

The energy intensity (kWh per MG of water treated) of desalination is at least 5 to 7 times the energy intensity of conventional treatment processes, so even though the population served by desalination is only about 3%, we estimate that approximately 18% of the electricity used in the municipal water industry is for desalination plants. Due to the lower energy consumption, RO processes are preferred to thermal treatments for domestic water desalinization in the United States. Energy consumption for common thermal and membrane desalination processes is shown in Table 2.5.

Table 2.5 Energy consumption of major desalination processes

Desalination Process	Energy Consumption kWh/m^3	Operating Method
Multi-stage Flash (MSF)	10 -15.5	Heat and vacuum
Multi-effect Distillation (MED)	5.5 - 9	Heat and vacuum
Vacuum Compression (VC)	8	Mechanical compression and vacuum
Seawater Reverse Osmosis (SWRO)	3 - 6	Pressure

In an RO process, costs associated with electricity are 30% of the total cost of desalinated water. Reducing energy consumption is critical for lowering the cost of desalination and addressing environmental concerns about GHG emissions from the continued use of conventional fossil fuels as the primary energy source for seawater desalination plants.

The feed water to the RO is pressurized using a high pressure feed pump to supply the necessary pressure to force water through the membrane to exceed the osmotic pressure and overcome differential pressure losses through the system (Stover, 2007). Typically, an energy recovery device (ERD) in combination with a booster pump is used to recover the pressure from the concentrate and reduce the required size of the high pressure pump (Stover, 2007; Jacangelo et al., 2013). A theoretical minimum energy is required to exceed the osmotic pressure and produce desalinated water. As the salinity of the seawater or feed water recovery increases, the minimum energy required for desalination also increases. For example, the theoretical minimum energy for seawater desalination with 35,000 milligrams per liter (mg/L) of salt and a feed water recovery of 50% is 1.06 kilowatt hours per cubic meter (kWh/m^3)(Elimelech and Philip, 2011). The actual energy consumption is larger as real plants do not operate as a reversible thermodynamic process (Elimelech and Philip, 2011).

The energy required for desalination using RO membranes is a function of the feed water recovery, intrinsic membrane resistance (permeability), operational flux, feed water salinity and temperature fluctuations, product water quality requirements, and system configuration (Subramani et al., 2011). The lowest energy consumption reported for an RO system is 1.58 kWh/m^3 at a feed water recovery of 42.5% and a flux of 10.2 liters per square meter per hour ($Lm^{-2}h^{-1}$)(Seacord et al., 2006). In addition, pre- and post- treatment contributes to additional energy requirements (Wilf and Bartels, 2005). Typically, the total energy requirement for seawater desalination using RO (including pre- and post-treatment) is on the order of 3 - 6 kWh/m^3 (Semiat, 2008; Subramani et al., 2011). More than 80% of the total power usage by desalination plants is attributed to the high pressure feed pumps (Wilf and Bartels, 2005). The energy consumption associated with filtration systems increases due to fouling by nanoparticles as reported in a study from the Energy Commission (Rosso and Rajagopalan, 2013). For example, flux analysis of MF 200 nanometer (nm) pore size membranes showed that particles between 100 and 2.5 nm contributed the most to the membrane fouling, more than fouling due to cake formation. Further understanding of the mechanisms of membrane fouling and of pretreatment options with coagulants will offer energy savings opportunities for water and water reclamation utilities (Rosso and Rajagopalan, 2013).

Energy management during desalination consists of various methods as summarized in the Table 2.6 below.

Table 2.6 Energy management approaches during desalination

Method	Approach
Enhanced system design	▪ Single stage configuration and reduction of pressure drop ▪ Internal staging design (ISD) configuration ▪ Uniform flux distribution within pressure vessel ▪ Center port pressure vessel design
High efficiency pumping	▪ Use of high speed and high flow pumps with low total dynamic head ▪ Centralized feed pumps for large skids ▪ Use of VFDs
Energy recovery	▪ Use of energy recovery devices (ERDs)
Advanced membrane material	▪ Use of thin film nanocomposite (TFN) membranes ▪ Carbon nanotubes and biomimetic membranes
Application of innovative technologies	▪ Forward osmosis ▪ Ion concentration polarization ▪ Capacitive deionization

2.2.4.1 Enhanced system design

Design and configuration of the membrane unit can have a significant effect on the performance and economics of the RO plant. A two-stage system results in a high feed and concentrate flow, thereby reducing concentration polarization. Due to the higher feed flow, greater feed pressure is required to compensate for the increased pressure drop across the RO train. Design efforts to reduce power consumption have resulted in the use of single-stage configurations for high salinity feedwater applications (Wilf and Bartels, 2005). Another innovative design to reduce the pressure drop involved the use of pressure vessel with center port design (Van Paassen et al., 2005) with observed 15% reduction in the feed pressure when compared to conventional side port design (Wilf and Hudkins, 2010). Optimization of energy consumption for RO treating high salinity feed water has also been performed by using a two-stage hybrid system with concentrate staging (Veerapaneni et al., 2005).

2.2.4.2 High efficiency pumping

The use of high speed and high flow pumps at lower total dynamic head would result in optimal speed for highest efficiency. For large RO plants the flow can be increased by centralized feed pumps that feed either larger skids or several smaller skids (Wilf et al., 2007).

Models of water lubricated, axial piston pumps (APP) are claimed to have high mechanical reliability and high efficiency while delivering pressures in the range needed for high salinity feed water RO applications (MWH Global, 2007). To accommodate variability of feed pressure with time (due to salinity and temperature fluctuations), without the necessity to throttle high pressure pumps or energy recovery devices, a VFD is incorporated into the electric motor unit that drives the high pressure pump (Wilf and Bartels, 2005). All of the above mentioned pumping methods have been known to significantly improve efficiency and reduce energy requirements.

2.2.4.3 Energy recovery

Energy consumption for RO desalination processes can be reduced by using ERDs (Jacangelo et al., 2013). The energy of the RO concentrate can be recovered by passing the concentrate stream through ERDs. The fraction of power recovered by the ERD depends on the type and efficiency of the equipment used. Four broad categories of ERDs are available and include: Pelton Wheel Turbine (PWT); Reverse Running Turbine Pump (RRTP); Turbo-Booster Pump (TBP); Pressure or Work Exchanger (PWE) systems. Typically, the first three are isobaric ERDs and achieve higher efficiency than centrifugal ERDs.

2.2.4.4 Advanced membrane material

Incorporation of zeolite nanoparticles in the polymer matrix of seawater RO membranes has resulted in enhanced flux of more than double that of a commercial product with 99.7% salt rejection. Incorporation of nanocomposite-based RO membranes has been reported to result in 20% lower energy consumption. The use of carbon nanotubes have also shown to consume lower energy when compared to conventional seawater water RO desalination (Holt et al., 2006). A ten-fold permeability increase is expected using a carbon nanotube RO membrane resulting in 30-50% energy savings. New developments have also been seen in the use of biomimetic membranes for desalination, designed to mimic the highly selective transport of water across cell membranes.

2.2.4.5 Innovative technologies

New technologies utilizing the principles of separation technology with membranes and electric field have been introduced in the recent years. These technologies have the potential to offer substantial reduction in energy consumption for desalination. For example, in the forward osmosis process, instead of using hydraulic pressure, as in conventional RO desalination process, a concentrated draw solution is used to generate high osmotic pressure, which pulls the water across a semipermeable membrane from the feed solution (McCutcheon et al., 2005). The energy utilization by the forward osmosis process has been reported to be approximately 25 – 45% of the thermal energy needed by multi-effect distillation. Forward osmosis has the added capability of using heat at a much lower or higher temperature than multi-effect distillation processes. Ion concentration polarization has been utilized to desalinate seawater using an energy efficient process (Kim and Choi, 2010) and has been reported to consume approximately 3.5 kWh/m^3 of energy (Kim and Choi, 2010). In capacitive deionization technology, a saline solution flows through an unrestricted capacitor type module consisting of numerous pairs of high-surface area electrodes and energy consumption as low as 0.1 kWh/m^3 has been reported using this technology (Welgemoed, 2005).

R&D opportunities for energy management in desalination have been highlighted in various reports and listed below.

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Energy Management Opportunities in Desalination

- Energy minimization strategies in desalination should also focus on optimization and reduction of energy in pre- and post-treatment processes. These processes contribution almost 10% of the total energy consumption. Reduced pumping and maintenance requirements through process optimization will be important to reduce energy consumption in these processes.
- Methods and approaches to the mass production of new membrane material are required. Only nanocomposite membranes have been commercialized for desalination. The implementation of carbon nanotubes and biomimetic membranes will require a higher packing density to make these new membranes cost comparable with conventional thin film composite membranes.
- Develop innovative technologies that focus on the robustness of the process. Innovative technologies developed thus far show promise for energy minimization but long-term operational stability and consistency with real water sources has not been proven with these systems. In addition, scale-up of these innovative processes is questionable.
- Develop technologies and practices that can reduce the energy demand of desalination and lower its environmental and economic costs (AWE and ACEEE, 2013).
- Develop and evaluate low energy desalination systems (Environmental KTN, 2008 (2008).
- Further understanding of the mechanisms of membrane fouling and of pretreatment options with coagulants will give energy savings opportunities for water and water reclamation utilities (Rosso and Rajagopalan, 2013).

2.3 Water and Electric Utility Integrated Planning

In 2013, the WEF's Energy Roadmap identified the need for a "*Collaborative Partnership*" between the water/wastewater utilities, electric utilities and communities for a successful management of energy and water resources (Liner and Stacklin, 2013). It is important that utilities in the water industry and power utilities engage in a collaborative planning and joint activities. Integrated planning of water and power can help to address issues associated with capital improvement financing, since electric utilities may find it favorable to offset the initial capital costs of energy projects in water and wastewater facilities for additional supply that will bolster their renewable portfolios over the long term. Policies and approaches are needed to encourage the water and energy sectors to move toward integrated resource management. Water and wastewater utilities seeking to lower their GHG emissions, may negotiate with their electric utilities or independent power producers to receive energy from cleaner or renewable sources than typical fossil fueled generation.

An ongoing effort by the WRF in partnership with NYSERDA (*Water and Electric Utility Integrated Planning*) will provide a resource for water utilities to engage in integrated planning and will identify new supporting research opportunities (Conrad, forthcoming). Further research should promote partnerships between electric and gas utilities with their water utility counterparts to successfully implement mutually beneficial programs (AWE and ACEEE, 2013). In the past years, joint collaborations between the water and electric utilities have been limited by the lack of mutual understanding of their respective operations and needs. There are also conflicting interests and objectives of both counterparts which contribute to this limited collaboration (The Johnson Foundation, 2013).

To advance joint opportunities between the water and power sectors, research should be conducted to foster communication through cross-sector task forces, expand outreach and information exchange between the two sectors, identify the tangible benefits to each party, identify new collaboration opportunities and the barriers/constraints that limit joint efforts, and understand both parties' risks and disincentives. Opportunities should be identified to design and construct cutting-edge, integrated infrastructure and develop joint pilot projects and programs. Partnerships with energy providers may be particularly useful in identifying cost savings related to electric rate structures and time-of-use programs issued by the energy providers (Leiby and Burke, 2011). Other research opportunities are in the development of formal programs directed by a mix of professionals from the water and wastewater industry along with electric utility representatives to study and demonstrate innovative energy management solutions and to disseminate knowledge (Wilcoxson and Badruzzaman, 2013).

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Integrated Planning

- Continue investigations into the water energy tradeoffs of differing resource development and management choices that can better inform multi-sectorial integrated resource planning (CRS, 2014).
- Identify rate structures, price constructs, and financing mechanisms that eliminate the financial disincentives of efficiency programs and alternative supplies use in the water sector planning (CRS, 2014).
- Identify and eliminate regulatory barriers to co-implementation of efficiency programs in the water and energy sectors such as policies in some states that restrict electric and gas utilities from utilizing biogas that is recovered from wastewater utilities. (CRS, 2014). Analysis is needed of incentives, disincentives, and lack of incentives to investing in cost-effective energy or water efficiency measures.
- Develop tools to evaluate the water energy trade-offs of differing resource development and management choices that can better inform multi-sectorial integrated resource planning (AWE and ACEEE, 2013).

2.4 Benchmarking Tools and Models

2.4.1 Auditing, Monitoring and Benchmarking

Improved data collection and auditing is integral for water and wastewater utilities seeking to identify appropriate actions to reduce costs, improve operations, and reduce their energy use. Energy records in water and wastewater treatment facilities and new assessment of energy use are needed to identify opportunities for improvement and prioritize energy management programs and strategies. Consistent data collection methodology is needed for benchmarking and allows comparison of water and energy data across and within sectors. This information enables water and wastewater managers to make decisions for achieving significant energy demand reductions, enhance energy production and simultaneously deliver reliable water-related services.

Few studies exist that audit the intrinsic energy in water and wastewater systems and there is not such an assessment at a regional or national level. Most of these studies are rarely performed in the context of the overall system operations and often focus on the evaluation of individual system components. Detailed energy audits can identify capital and operational improvements, can be conducted on plant designs and can identify renewable energy opportunities. As an example, MassDEP (*Massachusetts energy management pilot for drinking water and wastewater treatment facilities*) and NYSERDA, which were able to achieve zero-net or near zero-net energy use at their wastewater treatment plants, developed energy and water use benchmarks by a massive collection of data (AWE and ACEEE, 2013). Examples of system audits that have been commonly applied by water and wastewater utilities (Horne et al., 2011) are reported in Table 2.7. A recent report by the WRF and EPRI (Arzbaecher et al., 2013) developed appropriate metrics for energy use in water and wastewater by treatment process and plant size that might be useful for auditing.

The Energy Use Assessment Tool developed by EPA for small and medium water and wastewater utilities, for example, was piloted in 2011 and supposed to be ready for potential widespread marketing in 2012. The American Water Works Research Foundation (AwwaRF) Index/EPA *Energy Star – Electricity Usage Benchmark* developed a statistical basis for the EPA energy star performance rating for wastewaters. The American Socieity of Heating, Refrigeration and Airconditioning Engineers (ASHRAE) Tiered Energy Audits (Level I through Level III) and the Renewable Energy Assessment are used to identify operational and equipment changes for efficiency, and to discuss renewable energy options (Horne et al., 2011).

While a number of fact sheets, guides, and manuals have been published related to energy efficiency, there seems to be a lack of applicable tools for small and medium-sized utilities with regard to conducting an energy audit and baseline identification (Leiby and Burke, 2011)**.** As highlighted in the Rothausen and Conway publication on Nature Climate (2011), there is a lack of studies assessing energy use and related GHG emissions assessment in the whole water and wastewater sector (Rothausen and Conway, 2011). A number of reports from different organizations have highlighted the importance of benchmarking and development of energy indices in water and wastewater systems. A benchmark can provide facilities with targets for energy use, can help a facility track its energy performance and provide feedback on effective energy management and programs. The WERF has been carrying out a study in parallel with an EPRI study to develop energy use data for a wide range of wastewater treatment facilities, with a focus on developing energy benchmarks (Tarallo, forthcoming). The WERF study and the EPRI study complement each other by developing energy benchmarks based on engineering design calculations and best practices and by providing energy intensity values for various unit processes, respectively.

In general, there is a need for comprehensive studies and associated guidelines to conduct detailed audits of embedded energy demands and consumption for water and wastewater utilities at the local and national level in order to determine system optimization opportunities. Such studies could be expected to include benchmarking system components performance and dependencies, number of accounts and amount of service, geographic conditions, and projected demands over time of water/wastewater services. In addition, new research could also produce guidelines or protocols for water and energy industry-accepted assessments. Many challenges still need to be addressed, which may open opportunities for new research and development studies.

Table 2.7 Example of audits

Audits	General Information
EPA Energy Self-assessment tools	▪ ENERGY STAR Portfolio Manager, for water and wastewater utilities. ▪ Energy Use Assessment Tool
Non-EPA Energy Self-assessment tools	▪ NYSERDA Water and Wastewater Focus Program - Wastewater Benchmarking Tool - Water and Wastewater Self-Audit checklists ▪ CEE Water and Wastewater Self-Audit Checklists ▪ Mass Energy Insight
ASHRAE Tiered Energy Audits	▪ Level I (Walk-Through Analysis) ▪ Level II (Energy Survey & Analysis) ▪ Level III (Detailed Analysis of Capital –Intensive Modifications, aka Process Audit)
Renewable Energy Assessments	▪ Simple Discussion of Alternatives ▪ Desktop Analysis ▪ Feasibility Study
Power consumption and metrics	▪ Utility bill analysis ▪ Benchmarking
HVAC/Mechanical system audit	▪ Evaluate gas requirements (process & heating systems) ▪ Evaluate ventilation (efficiency & effectiveness) ▪ Controls (programmable thermostats, etc.)
Electrical system audit	▪ Motor efficiency/type ▪ Variable frequency drives ▪ Lighting (systems, bulb type, controls)
Process system audit	▪ Process improvement ▪ Operations optimization ▪ Efficiency planning

Adapted from Horne et al., 2011

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE
Monitoring, Auditing and Benchmarking

- Develop comprehensive studies and associated guidelines to conduct a detailed audit of embedded energy demands for an entire local, regional or national water/ wastewater system for purposes to determining system optimization (CRS, 2014).
- Develop baselines for comparison purposes, especially when variations in influent flow and composition and on discharge requirements differ (AWE and ACEEE, 2013).
- Gather energy data and model these data at a process level to enable the industry to set achievable targets and measure net environmental impact of any action (Environmental KTN, 2008).
- Develop adequate databases and monitoring and tracking systems for managing energy usage, measuring success, and formulating new energy efficiency strategies (Leiby and Burke, 2011).
- Design a software tool to facilitate estimation of plant level energy intensity and annual energy use by aggregation of unit operations (Wilcoxson and Badruzzaman, 2013).
- Further understand where energy is used in water and wastewater infrastructure facilities, what opportunities for improvement exist, and how to establish priorities for action. Develop standards for data collection, coordination, and quality control (CRS, 2014).

2.4.2 Tools and Decision Frameworks

A number of web-based or spreadsheet-based analytical and decision tools have been developed by various research organizations to assist their subscribing water and wastewater utilities in reducing energy costs, energy use and GHG emission reduction. Table 2.8 lists and provides a brief description of selected key energy and emission management tools that have been recently developed to reduce or recover energy and improve operations.

The *Decision Support System for Sustainable Energy Management* Tool, which helps utilities to understand the best way to achieve energy reduction goals and identify alternatives to non-renewable options has been pilot tested by four utilities. With this tool, the Jacksonville Electric Authority, an electric, water, and sewer utility in Florida compared options for biosolids handling and assessed their potential to meet the utility's energy goals. The tool allows a user to define economic, social, and environmental objectives as part of the Triple Bottom Line (TBL) goals (Conrad et al., 2011). Because these goals are not always quantifiable, a qualitative scale was used in the evaluation of options to achieve the TBL goals.

The following DOE tools: Pump System Assessment Tool and MotorMaster+ were used at the Metropolitan Syracuse Wastewater Treatment Plant for process optimization and were able to save about 2.81 million kWh per year (AWE and ACEEE, 2013). A recent WRF study reviewed existing tools for energy and greenhouse gas emission management for water utilities worldwide and identified ways on how to use them to support management decisions at water utilities (McGuckin et al., 2013).

Life Cycle Assessment (LCA) tools have been recently introduced for quantifying the embedded water and energy in water treatment systems (He et al., 2013). Rothausen and Conway (2011) emphasized the importance of analyzing the energy use and emissions of different water supply systems using an approach that combines LCA, commercial databases and economic calculations to impact the decision-making processes. More comprehensive assessments, and more standardized methodologies will enable comparison of different experiences internationally, and of different technologies and process (Rothausen and Conway, 2011). The same study listed a number of studies that quantified energy use and related GHG intensities from water supply and water and wastewater treatment through LCA assessment. These methodologies assist in assessing the environmental impacts (specifically quantifying the embedded water/energy) of a water treatment system and serve as a foundation for making better-informed decisions, improving the environmental aspect of products and services and selection of relevant indicators of environmental performance. LCA methodologies have been applied to provide guidance and framework for greenhouse gas (GHG) and water footprint assessment in the water and wastewater industry. Rarely do these LCAs include a detailed account for materials and consumables used in water treatment processes; in addition detailed Life Cycle Inventories (LCI) are lacking (He et al., 2013). The Water Energy Sustainability Tool (WEST), a LCA tool developed in a recent study by the Energy Commission (Horvath and Stokes, 2013) allows utilities to perform a more comprehensive energy and environmental LCA of all stages, from water supply infrastructure design to system production.

An ongoing joint project from the WRF and WERF is further developing the Green Energy Life Cycle Assessment Tool (GELCAT) originally developed by WERF to assist water utilities in evaluating the economic viability, and energy and environmental benefits/costs of the renewable options including micro-hydroturbines and geothermal energy, and beta testing GELCAT version 2 at water facilities (Lorand, 2013).

Table 2.8 Selected analytical and decision tools for energy reduction, recovery and generation in water and wastewater utilities

Tool	Tool General Information
DSS ***Decision Support System for Sustainable Energy Management***	Helps water utilities make better and more sustainable energy management decisions on developing a portfolio of options (with priority on renewables) to achieve energy management goals in a most cost-efficient manner (Conrad et al., 2011).
GELCAT ***Green Energy Life Cycle Assessment Tool***	Evaluates the suitability of solar, wind, or hydropower generation, associated technology cost and performance, information on the electricity generated, operating cost savings (payback period), greenhouse gas reductions, and life cycle costs (Lorand, 2013)
CHEApet ***Carbon Heat Energy Assessment Plant Evaluation Tool***	Plant-wide energy model that quantifies plant operating energy requirements and predicts the carbon footprint from wastewater treatment plants operated under an array of common process configurations (Crawford, 2011a). Demonstration of this tool is presented in Crawford, 2011b.

Tool	Tool General Information
LCAMER ***Life Cycle Assessment Manager for Energy Recovery***	Enables informed decisions on the feasibility of recovering energy (as biogas) from anaerobic digestion of wastewater solids at wastewater treatment plant (Monteith, 2011).
CHP-SET ***Combined Heat and Power System Evaluation Tool***	Evaluates CHP system performance and calculates total system efficiencies, inclusive of appurtenant equipment electrical demands, to produce electricity and collect heat and related emissions (Willis, 2011).
PSAT ***Pumping System Assessment Tool***	Helps water utilities to assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.
WEST ***Water Energy Sustainability Tool***	Used by water and wastewater utilities to improve design, planning and operational decisions. It is an Excel-based decision support tool that calculates the life cycle energy and environmental implications of infrastructure associated with the California water and wastewater sectors.
ESAT ***Environmental Sustainability Assessment Tool***	Helps water utilities to compare the sustainability performance of different water and sewage servicing options in terms of energy use, water use, GHG emissions, nutrient discharge, physical footprint, and life cycle cost.
Energy Benchmark ***Metric Score Sheets***	Establishes a comparative energy benchmark for a utility and provides energy metrics and a benchmark score, and indication of energy reductions needed to improve score
The Greenhouse Gas Protocol Initiative	Developed by the World Resources Institute and World Business Council for Sustainable Development, identifies the GHG emissions from energy use, electricity, heat and steam.
Urban Water to Air Model	Developed by the Pacific Institute, it calculates the energy and air impacts of strategic/tactical water management decisions and calculates air emissions based on various power sources and mixes.
Workbook for Quantifying Greenhouse Gas Emissions	Strategic, tactical and operational: calculates GHG emissions to meet United Kingdom reporting requirements (meeting DEFRA CRC).
Seawater Desalination Energy Consumption Modeling	Establish relationships between operating parameters and treatment process performance for key components of the overall desalination process. Provide specific guidance identifying the impact of source water quality, membrane selection, and variations in operation on energy consumption (Ghiu, 2014).
TERRY ***Tool for Evaluating Resource Recovery***	Under development by the Latimer, 2014 project as guidance for wastewater utilities seeking to evaluate resource recovery opportunities on-site, such as for nutrients.

Additional research has been identified in Conrad et al., 2011 work and other studies (He et al., 2013; McGuckin et al., 2013), which would provide a systematic way to develop opportunities and improve energy management practices at water and wastewater utilities. Research in this direction should be further performed and new research opportunities are highlighted below.

RESEARCH OPPORTUNITIES IDENTIFIED IN LITERATURE

Tools and Decision Frameworks

- Perform life cycle studies for the nutrient recycling technologies, especially for urine separation, controlled struvite precipitation and nutrient recovery through aqua-species.
- Identify better financial comparison metrics (that go beyond the simplistic payback period analysis) that consider the full life cycle of a potential energy project and that create a better picture for its long-term value.
- Provide a systematic methodology to develop a possible set of options for achieving goals, which are more specific to each utility applying DSS tools.
- Provide a method for calculating the economic value of each alternative, using criteria that are more specific to each utility.
- Carry out an assessment of the potential for energy recovery and generation from the water and wastewater industries (Wilcoxson and Badruzzaman, 2013).
- Identify how water utility governance would be affected if supporting energy management strategies or how it interferes in the implementation (which regulations require attention, etc.).
- Improve LCA analysis by expanding the LCA Data collection tool, determining high priority data, and integrate LCI assessment on existing or new LCA methodologies since LCI data is important for estimating embedded water and energy and increase accuracy of LCA estimations.
- Conduct power supply sensitivity analysis for various power supply alternatives, such as wind, solar, biogas, to evaluate environmental impacts generated by various power supply sources.
- Conduct case study and demonstration studies on the investigation of embedded water and energy associated with various water supply alternatives (e.g., imported water, brackish water, desalination, and indirect potable reuse).
- Identify best practices in terms of measurement, control and automation, including intelligent systems, novel sensors, process control and optimization models Environmental KTN, 2008).
- Incorporate full GHG emissions benchmarks into a combined energy and GHG benchmarking tool. At present most energy benchmarking tools include only GHGs that originate from the consumption of energy, and do not include other sources of GHGs.
- Develop improved process control, automation, decision support tools, condition monitoring and intelligent remote metering technologies for on-line efficiency improvement Environmental KTN, 2008).

2.5 Social and Institutional Issues

2.5.1 Strategic Management

The implementation of high-level management policies and strategies, as pointed out in the "Strategic Management" section of WEF's *The Energy Roadmap: A Water and Wastewater Utility Guide to More Sustainable Energy Management*, are needed to achieve sustainable energy management in water and wastewater utilities (Liner and Stacklin, 2013). Strategic Energy Management (SEM) is emerging as a new focus area for the water and wastewater industry that involves engaging the broader organization in a structured way to make lasting energy efficiency improvements (Arzbaecher et al., 2013). Facilities that engage a SEM approach can achieve savings in the 2-20% range, with savings usually about 4-5% that exclude other equipment-based energy efficiency improvements (Arzbaecher et al., 2013). Water and wastewater organizations interested in formalizing their SEM practices can pursue the implementation of the ISO 50001 Standard for Energy Management Systems. ISO 50001 essentially codifies SEM, collecting the set of SEM practices into a framework that is comparable internationally between facilities and that is certifiable by third party registrars (Arzbaecher et al., 2013). Plants that implement ISO 50001 achieve energy efficiency gains and improved energy management by developing policies and energy savings targets, making informed decisions about how best to use energy resources, and measuring results to compare with established targets (Arzbaecher et al., 2013). SEM elements needed for utilities to implement energy projects are:

- Gaining executive buy-in;
- Committing to and setting a goal for energy or carbon reduction;
- Initiating an energy team to act on energy projects;
- Engaging employees to take action and suggest improvements;
- Focus on operations and maintenance of equipment, not only on replacement;
- Using long-term energy savings over the equipment life cycle to justify designs that save energy;
- Considering energy use on all capital projects' design;
- Conducting a GHG emission analysis;
- Setting internal price for carbon;
- Setting and tracking performance indicators; and
- Benchmarking data to compare to other wastewater utilities.

Education and training of staff and operators regarding the implementation of new methods, technologies and systems is needed for a successful implementation of energy efficiency programs. Commitment to an energy program should find agreement from all departments in the organization and often an interdepartmental energy implementation team working across all levels can facilitate the development of energy program at the specific utility (Liner and Stacklin, 2013; WEF, 2012). Organization levels that should be involved in the effort and should give inputs for the program implementation include management team, operators, financial administrators and energy utility representatives. In particular, an optimal management structure, management support and operator and staff buy-in is critical for long-term success in reducing energy consumption. It is important that management and engineers consider the alternative perspectives of these different occupational groups when planning on implementing new programs or technologies.

When moving towards innovation and technology, utilities face an important cultural change. Managers, engineers and operators rely on different cognitive models for adapting to a new program or technology, which often give rise to conflicting perspectives (Von Meier, 1999). In water utilities, resistance from the operations team towards installation of full system control automation is often encountered. An example of cultural change was observed in water utilities implementing and subsequently operating an EWQMS (Badruzzaman et al., 2015). Although some operators were engaged with the program, others preserved their conservative and empirical mode of operating the system (Chan, 2013). Their acceptance towards new technologies is important since they are held responsible for safe operation without outages.

Water and wastewater utilities are seeking training program models, guidebooks, and tools that can help disseminate the knowledge on energy management and efficiency across the organization. The *Energy Roadmap* published by WEF, serves as a guide for utilities of all sizes to pursue sustainable energy management in their facilities (WEF, 2012). The Oregon Association of Clean Water Agencies implemented a 13-month energy management training program for water utility managers on sustainable energy management (The Johnson Foundation, 2013).

Communications efforts should be widespread outside the organization and inform all parties involved in the implementation of the energy management program, such as the scientific community, the stakeholders, policymakers and the general public. This approach will surely facilitate collaboration among researchers, the organization and regulators (Hightower et al., 2013). In addition the public plays a major role when a water or wastewater utilities is seeking to reduce its energy consumption. In terms of public understanding and behavior change, a report from the Pacific Institute showed that there is potential to raise awareness about the linkages between water and energy and to modify carbon/water footprinting approaches by developing a website for the private consumer and a home water–energy–climate calculator (WECalc) tool that provides a detailed analysis of domestic water use, related energy use and GHG emissions based on user inputs (Rothausen and Conway, 2011).

RESEARCH OPPORTUNITIES

Organizational Culture and Communications

- Develop effective engagement and communications methods, practices forums, and mechanisms to ensure commercialization and adoption of preferred research results and technological developments that maximize acceptance and application in the organization, marketplace and public service industry (AWE and ACEEE, 2013).
- Develop supply chain and product embedded water-energy evaluations that can inform consumers of the energy and water intensity of the products or services they

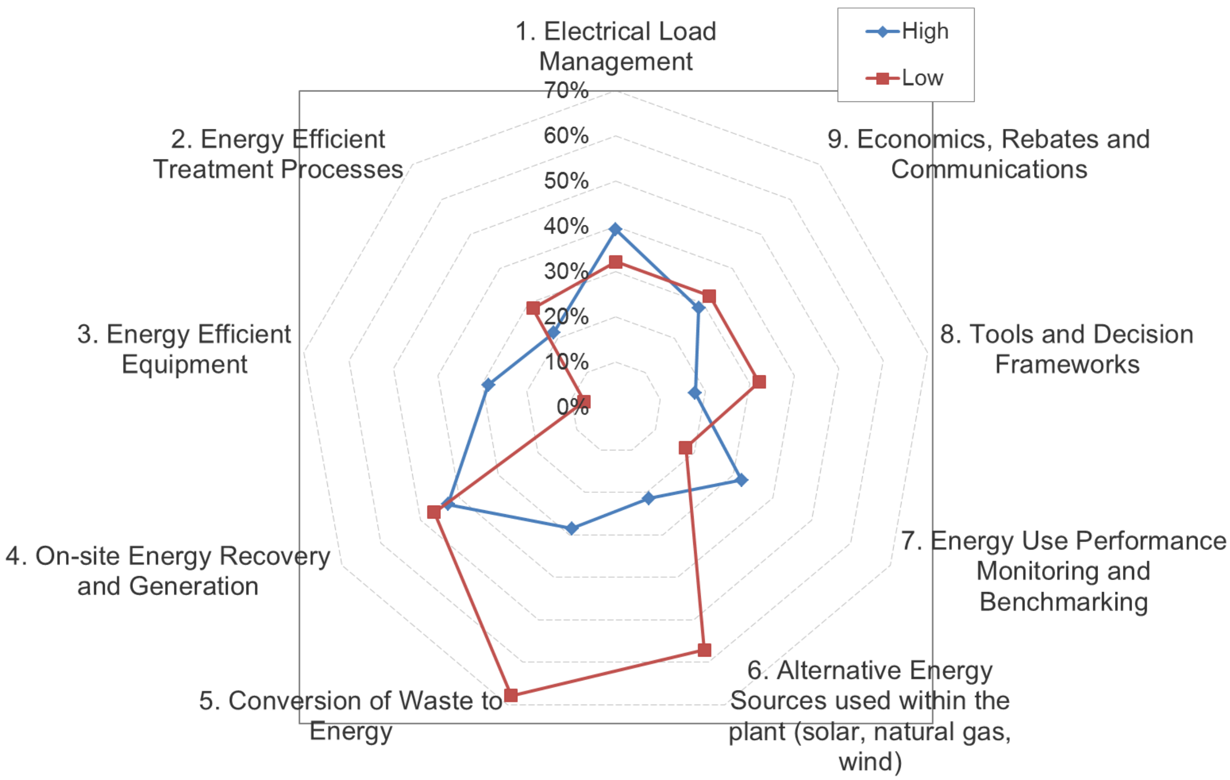
2.6 Questionnaire Results

The previous sections have provided an overview of energy management trends in water and wastewater utilities and have highlighted the research questions that resulted from recent reports and publications. This section highlights some of the findings collected through the questionnaire designed to gain additional understanding from water and wastewater utilities on the current state of implementation of energy programs, related implementation challenges and future research needs. A total of 36 responses from various organizations representing the interest of water and wastewater utilities were received. The questionnaire is included in Appendix B. The questions were formulated in the following nine major energy research categories:

- Electrical load management;
- Energy efficient treatment processes;
- Energy efficient equipment;
- On-site energy recovery and generation;
- Conversion of waste to energy;
- Alternative energy sources used within the plant (solar, natural gas, wind);
- Energy use performance monitoring and benchmarking;
- Tools and decision frameworks;
- Economics, rebates and communications.

One of the questions was designed to identify the level of resource allocation (e.g., labor, capital investments) that the respondent organizations made in the last five years for any energy related projects, including desktop studies, pilot and/or full-scale implementations. The respondents were asked to provide the level of allocation of resources in terms of high, medium and low. Figure 2.1 shows the percentage of respondents claiming a “high” and “low” allocation of resources in the nine different energy management categories. As shown, more than 60% of the respondents had a low allocation of resources to "conversion of waste to energy" and "alternative energy sources used within the plant". Alternatively, more than 40% of the participants had a high allocation of resources invested in the implementation of "on-site energy recovery and generation" and "electrical load management" categories.

Figure 2.1 Percentage of respondents claiming a "high" and "low" allocation of resources to implement energy projects in nine different energy management areas



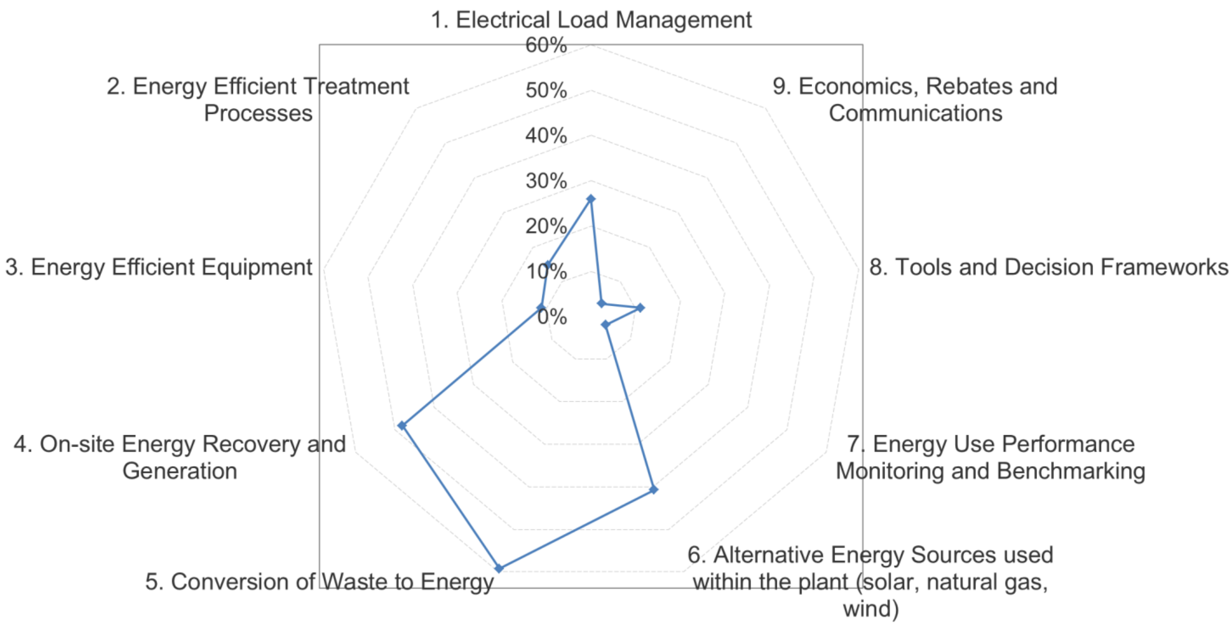
The questionnaire respondents expressed concerns and encountered some obstacles in implementing energy projects in various areas. From a deeper examination of the responses, some of the major challenges encountered by the respondents in the categories considered above were:

- Institutional barriers, cultural resistance to implementation of energy programs, and lack of organizational commitment;
- Cost and lack of capital funding;
- Lack of time and resources (land, labor, expertise, trainings);
- Risk (process interruption, water quality impacts, etc.);
- Regulatory and compliance with water discharge permits and air regulations;

- Lack of commercial and proven technologies, tools, frameworks; and
- Lack of government programs and incentives from state and electric utilities.

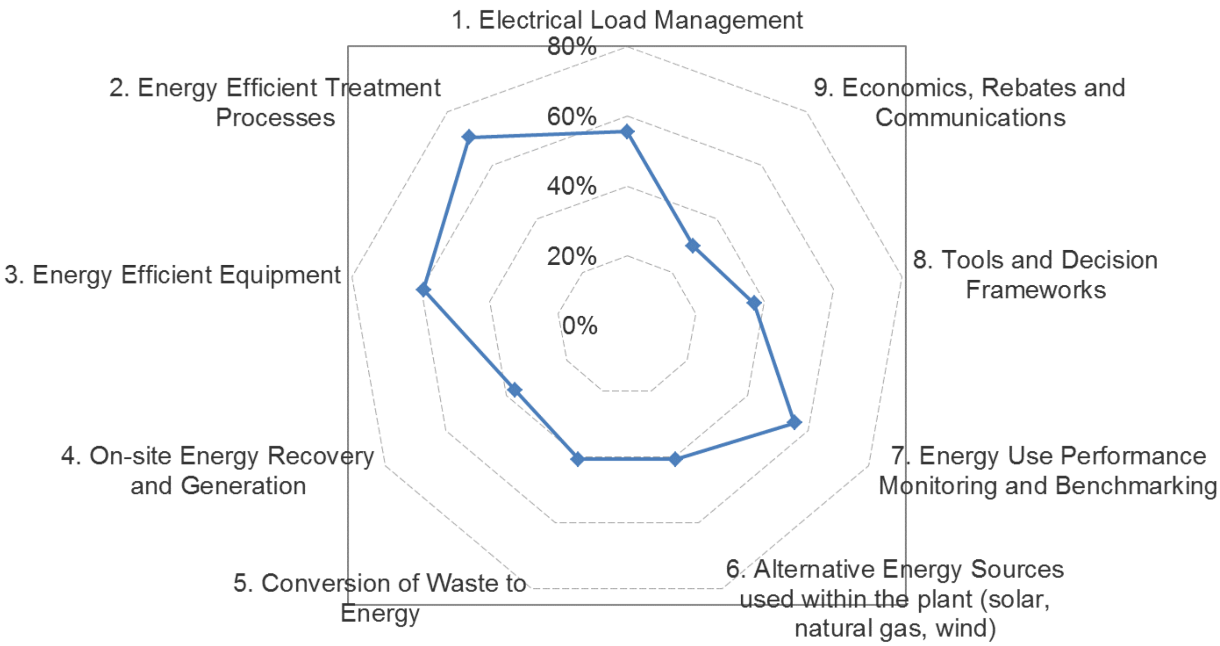
Respondents were asked to provide a rating (high, medium, low) of each of the nine research categories based on the obstacles faced by their organization in implementing energy projects "in this area". Figure 2.2 shows the percentage of respondents rating obstacles as "high". As shown, approximately 60% of the respondents were highly challenged when implementing projects related to the "conversion of waste to energy", and more than 40% were highly challenged when implementing "on-site energy recovery and generation" and application of "alternative energy sources".

Figure 2.2 Percentage of respondents encountering "high" challenges in the implementation of energy projects in nine different energy management areas



Significant action and research is needed to boost the implementation of energy research programs at and for water and wastewater utilities. According to the questionnaire, as shown in Figure 2.3, respondents indicated their organization will highly benefit from further research in all of the energy management areas identified, with highest benefits identified in the categories of "energy efficient treatment processes" (70%), and "energy efficient equipment, "electrical load management," and "energy use performance monitoring and benchmarking" (~60%).

Figure 2.3 Percentage of respondents highly benefitting from further research in nine different energy management areas

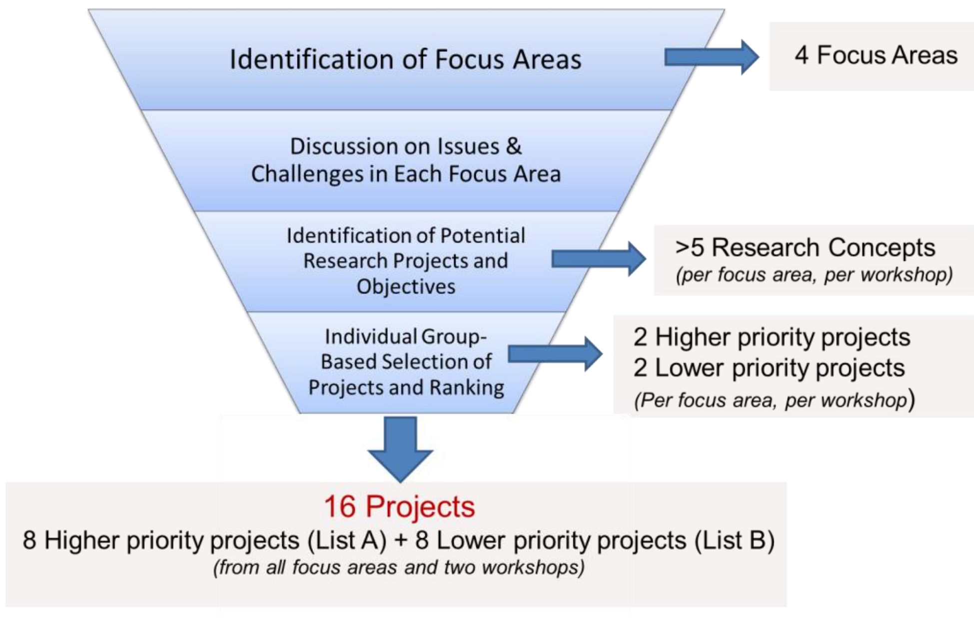


CHAPTER 3 :
Development of the Project Concepts

3.1 Introduction

This chapter summarizes the approach used to support the development of energy research project ideas for the water and wastewater industry and the outcomes of two interactive workshops convened in New York and California. The workshop outcomes include a number of future research opportunities and priorities, with related project descriptions, that can be incorporated into future request for proposals by the WRF, NYSERDA and the Energy Commission . The project approach used and discussed in this chapter is presented in Figure 3.1.

Figure 3.1 Approach used for the development of energy research project concepts in the New York and California workshops



Based on the findings of the literature review and the survey, the project team, with the PAC and the project participants, identified four primary research focus areas that were used to organize the breakout sessions of the workshop. The focus areas identified included:

- Energy management;
- Energy efficient equipment;
- Energy efficient processes; and
- Energy and resource recovery.

In both workshops, the participants were divided in four research focus area breakout groups. It should be noted that prior to assigning participants to their breakout group, the project team asked each participant to select their preferred focus areas based on their experience and interests. During the breakout discussions, each group was assigned a leader, a scribe, and a reporter. The leader ensured that the topics were covered and summarized within the allotted timeframe; the scribe captured and recorded the discussion items; and the reporter summarized the major points and presented them back to the entire group.

The breakout groups met in two different sessions, Breakout Session 1 and Breakout Session 2. The purpose of Breakout Session 1 was for each group to assess the current state of knowledge on various research topics within the research focus area, and identify the challenges/issues/trends and the associated opportunities/solutions. The purpose of Breakout Session 2 was for each group to identify at least five energy research project concepts in their focus area.

The groups were then asked to prioritize four projects out of the selected research project concepts, based on five criteria and the rating scale presented in Table 3.1. Based on the resulting ranking, each breakout group selected four projects including two top ranked projects and two bottom ranked projects. The top two were considered part of the "List A" (higher priority) projects whereas the remaining two were included in the "List B" (lower priority). The breakout groups then worked on developing detailed project descriptions for each of the four project concepts (See Chapter 4.) Thus, a total of sixteen project descriptions were generated for each workshop.

Table 3.1 Prioritization matrix with ranking criteria and rating scale

Criteria	Scoring Value
Likelihood of implementation at a larger scale	1: Low
	2: Medium
	3: High
Timeliness	1: Research needed after 5 years
	2: Research needed in 2-5 years
	3: Research needed in 0-2 years
Economic Benefits (*Cost savings*)	1: Low benefit
	2: Low to moderate benefit
	3: High benefit
Environmental Benefits (*GHG/Water use reduction*)	1: Low benefit
	2: Low to moderate benefit
	3: High benefit
Regulatory* Risk Management	1: Low benefit
	2: Low to moderate benefit
	3: High benefit

*Criteria considered during the New York workshop only.

The combined outcomes of Breakout Session 1 and Breakout Session 2 from the two workshops for each of the research focus areas are presented in the following sections.

3.2 Energy Management Project Concepts

For the breakout discussion, the participants in the Energy Management group were provided with some guidance on the topics to consider as a starting point for the discussion. The discussion topics included, but were not limited, to:

- Integrated energy load management programs for demand response;
- Alternative energy sources within the plant (natural gas, wind, solar);
- Energy and water quality management system (EWQMS);
- Water and electric utility integrated planning;
- Integration with other sustainability initiatives;
- Auditing, monitoring and bench-marking;
- Tools and decision frameworks;
- Organizational barriers/challenges.

The outcomes of the breakout group discussions are summarized in the sections below.

3.2.1 Challenges and Opportunities in the "Energy Management" area

During the first breakout session of the two workshops, the participants identified a number of challenges and trends that water and wastewater utilities are facing in relation to energy management. A number of these needs were used as input for the development of the research ideas during the second breakout session. Table 3.2 summarizes the topics and related discussion items that were covered during the first breakout discussions.

Table 3.2 Issues, challenges and opportunities highlighted in the "Energy Management" focus area

Discussion Topic	Discussion Items
Cultural issues and Communication	▪ Need to impose energy management/GHG reduction as strategic goals for the organization ▪ Increase internal communication between various organization levels (e.g., manager, engineers, operators, etc.) ▪ Lack of guidance and protocols for engineers and operators (e.g., pump selection) ▪ Need for training to increase expertise on energy management ▪ Need to develop operator certification programs for energy management and energy efficiency ▪ Obtain buy in from operators/staff ▪ Reward operators for reducing water costs and ensure a skill-based compensation ▪ Lack of simplified dashboard displaying the impact of operator's decision related to energy efficient operation ▪ Need to reduce restrictions from Unions on job descriptions ▪ Lack of equivalent to the United States EPA ENERGY STAR program specific to

Discussion Topic	Discussion Items
	water utilities ▪ Target Leadership in Energy Efficient Design (LEED)/ENVISION certifications for new and existing projects
Demand response	▪ Need coordination between water and electric utilities on pump operation under Demand Response programs ▪ Need to better understand the balance and trade-offs between water quality, energy management and electric load management ▪ Need to identify demand response programs available and understand their benefits and challenges ▪ Need to evaluate opportunities and challenges for energy management in real time market ▪ Need to develop guidance on peak demand shaving and understand its benefits (e.g., reduced size pumps, pipes, etc.) ▪ Determine impact of rate structure, customer demand response, and reduction of peak demand on infrastructure and efficiency ▪ Lack of knowledge on the safe level of water storage and impact on water quality ▪ Conventional treatment process not designed to adjust as quickly as the time-of-use operation imposed by the electric utilities ▪ Need for multi-pump operation and for pump selection optimization based on energy consumption
Alternative energy	▪ Lack of organizational commitment ▪ High payback period, particularly when there are no opportunities to offset the load ▪ Need for a standardized approach for the implementation of solar, wind, or any renewable energy type project ▪ Need for guidance on achieving zero emissions and balance it with infrastructure needs (competing needs) ▪ Need for demonstration projects with detailed breakdown of costs ▪ Lack of momentum for drinking water utilities for energy generation other than micro-turbines ▪ Need to understand the impact of plant size on the application of energy generation from wastewater utilities ▪ Need to boost renewable energy from anaerobic digester and co-digestion
Data Collection and Benchmarking	▪ Need for data collection protocols, data models, guidance on data analysis and development of Best Management Practices ▪ Need to improve data and SCADA management (e.g., schedule lift stations and prioritize activities (run times, maintenance) ▪ Lack of standardized practice on raw data collection from SCADA, analysis and validation ▪ Need for energy data and display dashboards in format useful to make decisions ▪ Link energy data to asset management ▪ Lack of performance metrics for cost and performance ▪ Lack of benchmarking and related metrics (e.g., pump energy consumption) ▪ Lack of energy index (actual/theoretical) ▪ Develop independent system operation (near real-time, web-based)

Discussion Topic	Discussion Items
Monitoring	▪ Need for power monitoring with submetering of individual processes ▪ Increase accuracy of meters through regular calibration and maintenance ▪ Lack of instrumentation specialist ▪ Need for Programmable Logic Controller (PLC) to control DO levels
Rate structure and end-users	▪ Need to shift from current rate structures to water conservation rate structure ▪ Need to develop a model for regulatory agencies to provide incentives for energy management ▪ Need to develop incentive programs for both water and energy conservation ▪ Lack of training, awareness and education ▪ Need guidance on the development of conservation programs for high energy and water use ▪ Need to understand the impact of decreased water use on pump efficiency and wastewater concentrations
Water and electric utility integrated planning	▪ Need to understand environmental and power regulations and their conflicting interests ▪ Need for model for regulatory agencies to provide incentive for energy management ▪ Need to improve collaboration between water and electric utilities to develop communication program for operators ▪ Need for sub-metering and understand the associated costs for water utilities ▪ Need for electric consumption data on a real-time/near real-time basis from electric utilities ▪ Need for electric utility data to be delivered directly to the water utility SCADA

3.2.2 Research Project Concepts in the "Energy Management" Focus Area

This section includes the project ideas developed by the participants within the "Energy Management" focus area in the New York and California workshops. A total of eleven project concepts were first developed. The title and objectives of these projects are presented below. Eight of the project ideas from the eleven concepts listed below were recommended by the participants for potential funding opportunities and were considered part of the "List A" and "List B" projects introduced in Chapter 4. The project descriptions, research approach, and related budget and schedules of the projects selected are presented in Appendix D.

1. Cost-benefit analysis of the application of SCADA and other data collection systems for energy management

PLC and SCADA systems are essential to collect useful information that has both an indirect and direct effect on energy efficiency and use. These data, when presented in the proper format, can be a useful tool for operators for process decisions and for budgetary purposes. The objectives of this project are to:

- Identify how utilities are using the data to focus on energy-focused efficiency opportunities and the costs and benefits of various power monitoring equipment and database tools;

- Evaluate the tools and methods of "real-time" energy monitoring at electric meter and sub-metering of specific equipment; and
- Discuss the best management practices observed followed by opportunities for improvement of the data collection and use with a primary focus for energy management.

2. Change management to address organizational barriers and promote/integrate energy efficiency

As energy costs rise and energy efficiency is becoming increasingly important within the water sector, the role of day-to-day operations and maintenance staff is changing. There is a need for operators to become proficient in energy data collection, analysis, and interpretation. However, there are several gaps between existing skill sets and training/experience to achieve this. While many utilities have and/or are developing Energy Management Programs, teams, and action plans, without institutional-wide understanding and prioritization of energy efficiency throughout all operations these programs are less likely to be successful. The objectives of this project are to:

- Identify and reduce organizational barriers to energy management programs and to better promote/integrate energy efficiency throughout the organization; and
- Evaluate the current level of energy management knowledge/practices among utility operators, what changes need to be made in terms of education/awareness, training, data collection, and the implementation of monitoring equipment.

3. Compilation of best management practices for energy management

Various reports and case studies, which currently exist in the literature, address discrete energy saving opportunities at water and wastewater facilities. However, there is not a single document identified that provides a comprehensive list of all potential energy saving opportunities, how they are or were implemented, and the potential energy savings of each opportunity. A guidance document addressing this issue would be very beneficial to engineers, operators, and energy managers in providing a resource that assists utilities in identifying and prioritizing energy saving opportunities in their own facilities. This compendium would be useful in providing support and justification for program development, approval, and implementation of energy reduction initiatives at utilities. The objectives of this project are to:

- Provide a guidance document that includes a compilation of the various energy reduction programs, program elements, and practices successfully implemented by water and wastewater utilities; and
- Provide specific details of each program element, categorized by facility type, size, and process.

4. Review of regulatory conflicts and recommendations for resolutions

Conflicting and/or prohibitive regulations prevent development of distributed energy projects at water and wastewater facilities. Conflicts exist between state power and environmental compliance regulatory bodies on most clean and efficient energy generation. In addition, air and energy regulators need to evaluate the impact of regulations on the highest and best use of water and wastewater (industrial) facilities that optimize energy, economic, and environmental benefits. The objectives of this project are to:

- Review the regulatory conflicts between air quality, energy, and GHG reduction goals; and
- Provide recommendations for resolution (as it relates to energy grid constraints and distributed energy resource integration with local utility energy infrastructure).

5. Development of a screening tool for prioritizing energy efficiency projects

Water and wastewater facilities can achieve multiple benefits by improving the energy efficiency of their new, existing, and renovated facilities and their day-to-day operations. By implementing energy assessments and audits, the utility can identify, evaluate, and prioritize potential energy improvement projects and activities and prepare a list of all of the projects that could be implemented to increase energy efficiency. The objectives of this project are to:

- Evaluate energy cost and consumption savings potential for each alternative and develop criteria for ranking; and
- Develop matrices for performance evaluation and evaluate the applicability of Envision for ranking.

6. In depth understanding of alternative energy sources for water and wastewater utilities

Wastewater utilities are becoming increasingly energy generating facilities, not only consumers of energy. For example, combined heat and power, also known as cogeneration, is a reliable, cost-effective option for wastewater treatment facilities that have, or are planning to install, anaerobic digesters. The objectives of this project are to:

- Investigate on-site generation for peak shaving, propose an economic bio-digester design and micro-turbine research; and
- Investigate emerging technologies for energy recovery for small plants and related cost benefits.

7. Evaluation of the conflicting interests of energy and water quality management and development of best management practices

Energy management strategy to decrease load or reduce overall energy costs can conflict with water quality goals for utilities. For example, to match time-of-use electric tariffs may conflict with flat treatment plant operations; required fire flow storage; water age and contaminant treatment standards. The objective of this project is to identify best practices (strategic, tactical programmatic design engineering) to successfully integrate water utility energy management and water quality objectives.

8. Development of universal data inventory (models) for pumps

Pumps represent 85% to 95% of all energy consumption for a water utility, yet there are few if any metrics on actual pump performance or a centrally accessible database for utilities to compare pumps with other utilities. Identifying poor performing assets is best done in comparison with other similar pump installations. The potential benefits available from various remediation options can be quantified along with return on investment (ROI) and GHG benefits. The objective of this study is to:

- Develop a universal data model for pumps and create an initial data set to allow for comparative analysis of pump performance. The comparative tool will allow selection of remediation options to indicate potential outcomes in terms of operating point, energy consumption and GHG benefits.

9. Development of a communications strategy for successful implementation of energy management projects

In its current state, there is a communication disparity between electric utilities and their water-wastewater customer segments, which commonly comprise a significant part of the electric utilities non-residential customer portfolio. This lack of mutual understanding between the electric and water industries, particularly on energy management, often lead to missed opportunities for potential partnerships and synergies that would prove mutually beneficial in areas such as environmental compliance, resource management, inter-agency relations and productivity. The objective of this study is to:

- Provide an array of successful communication strategies that address key points of an energy management project, and their value, to every level within and water/ wastewater utilities.

10. Impacts of emerging water quality regulations in energy management

From a regulatory standpoint, current and future requirements under the Clear Water Act (CWA) and Safe Drinking Water Act (SDWA) have the potential to impact the design and operation of water utilities. The objectives of this project are to:

- Review the emerging regulations for water quality (e.g., THM) and identify their impact on water utility operations/ treatment processes and related energy consumption; and
- Address cost implications of these new regulations.

11. Development of a roadmap to a zero emission water utility

Utilities across the nation are setting internal GHG emission reduction goals without having evaluated how best to achieve those goals. Successfully reducing GHG emissions requires careful planning, logistical and financial evaluations, as well as balancing competing priorities including aging infrastructure, water quality, and regulatory requirements. This project will:

- Help utilities develop meaningful direct and indirect GHG emission reduction goals, identify cost-effective GHG emission reduction strategies; and

- Assist utilities with the development of a roadmap to achieve those goals.

3.2.3 Scoring Results of Research Project Concepts in the "Energy Management" focus area

The Energy Management breakout groups sorted the proposed project concepts into an order of importance, based on five criteria and the rating scale presented in Table 3.1. Table 3.3 presents the combined results of each group's ranking obtained from the two workshops.

Table 3.3 Scoring results of project concepts developed in the *Energy Management* focus area

Project	Scoring Criteria					Final Score[2]	Recommendations
	Likelihood of Implementation	Timeliness	Economic Benefits	Environmental Benefits	Regulatory Risk Management[1]		
Compilation of best management practices for energy management	3	3	3	2	2	**13**	"List A" (based on NewYork workshop)
Review of regulatory conflicts and recommendations for resolutions	2	3	2	3	3	**13**	"List A" (based on NewYork workshop)
Cost-benefit analysis of the application of SCADA and other data collection systems for energy management	2	3	3	2	2	**12**	"List B" (based on NewYork workshop)
Development of communications strategy for successful implementation of energy management projects	3	3	3	3	-	**12**	"List A" (based on California workshop)
Evaluation of the conflicting interests of energy and water quality management and development of best management practices	3	3	3	2	-	**11**	"List B" (based on California workshop)
Development of universal data inventory (models) for pumps	2	3	3	3	-	**11**	"List A" (based on California workshop)
Change management to address organizational barriers and promote/integrate energy efficiency	2	2	2	2	1	**9**	"List B" (based on NewYork workshop)
Development of a roadmap to a zero emission water utility	1	2	2	3	-	**8**	"List B" (based on California workshop)
Development of a screening tool for prioritizing energy efficiency projects	1	1	2	2	1	**7**	Project not selected
In depth understanding of alternative energy sources for water and wastewater utilities	1	1	1	1	1	**5**	Project not selected
Impacts of emerging water quality regulations in energy management	1	1	1	2	-	**5**	Project not selected

[1] Scoring criteria not considered during the California workshop.

[2] The total scores between the NY and the California workshops are not consistent and should not be compared based on the numerical value reported.

3.3 Energy Efficient Equipment Project Concepts

For the breakout discussion, the participants in the Energy Efficient Equipment group were provided with some guidance on the topics to consider as a starting point for the discussion. The discussion topics included, but were not limited, to:

- Pump, motor, and VFDs;
- Advanced SCADA;
- Energy efficient HVAC;
- Application of micro-turbine in the distribution system;
- Application of energy recovery device in desalination;
- Energy sub-metering;
- Fine bubble diffusers;
- Performance monitoring sensors;
- Real-time monitoring equipment;
- Bench-marking and optimization of equipment.

The outcomes of the breakout group discussions are summarized in the sections below.

3.3.1 Challenges and Opportunities in the “Energy Efficient Equipment” area

During the first breakout session of the two workshops, the participants identified a number of challenges and trends that water and wastewater utilities are facing in relation to energy efficient equipment and technologies. A number of these needs were used as input for the development of the research ideas during the second breakout group. Table 3.4 summarizes the topics and related discussion items that were covered during the first breakout discussions.

Table 3.4 Issues, challenges and opportunities highlighted in the “Energy Efficient Equipment” focus area

Discussion Topic	Discussion Items
Microturbines	▪ Need for interconnection and synchronization with power grid ▪ High capital costs of the technology ▪ Low energy producing devices and no recent innovations on the technology ▪ Identify opportunities and critical success factors (location, proximity, etc.) ▪ Need to provide a framework for viability
HVAC/lighting	▪ Need to determine actual payback ▪ Need to achieve cost savings over life of equipment ▪ Need to explore geothermal coupled with HVAC

Discussion Topic	Discussion Items
Advanced SCADA	▪ Need to improve SCADA infrastructure ▪ Need to improve data management (acquisition/storage/retrieval/analysis) and data collection for specific objectives ▪ Need for higher technical knowledge at the operations level ▪ Need for enhanced use of real-time data ▪ Need for advanced weather notification (e.g., rainfall) ▪ Need to determine capital and O&M costs, and payback period ▪ Need for smart SCADA for improving treatment processes due to changes in raw water quality ▪ Need for the development of performance-based PM/CM
Equipment	▪ Need for guidance on equipment selection and procurement requirements ▪ Need for a life cycle based procurement selection process framework and development of performance guarantee ▪ Need to determine the lifespan of equipment and the impacts of aged equipment on energy consumption ▪ Need guidance on matching equipment to ancillary equipment ▪ Need for a roadmap for the basis of operation and development of operating parameters ▪ Improve overall maintenance and identify equipment issues ▪ High cost for equipment and in-house equipment maintenance, particularly for small utilities ▪ Need to improve pumping allowing necessary turndown ▪ Need to evaluate true motor efficiencies of turbo aerators ▪ Need to determine wire to water efficiency and planning for system growth/expansion
Monitoring	▪ Need for condition assessments of equipment and aboveground facilities (alignment, vibration thermal, oil testing, etc.) ▪ Improve monitoring for optimization of individual pumps, storage and processes ▪ Improve overall energy management and process control ▪ Need for predictive maintenance tools ▪ Need monitoring for influent characterization ▪ Need to determine actual pump efficiencies ▪ Enhance solids management ▪ Improve aeration control and energy saving in BNR plants ▪ Improve assessment of chemical savings and usage
Benchmarking	▪ Improve data collection (water quality, treatment requirements, technologies used, etc.) ▪ Evaluate wire to water efficiency ▪ Need for pumping and individual processes benchmarking ▪ Understand the baseline energy performance of processes ▪ Identify breakdown of energy costs by process area
Aeration	▪ Understand micro-bubble technology impact on energy demand ▪ Need for minimizing aeration input to achieve effluent quality ▪ Need comparison for ammonia and DO based control ▪ Move away from a surrogate to the parameter of concern ▪ Need for case studies

Discussion Topic	Discussion Items
Sludge Digestion	▪ Increase focus on digester and/or process tank mixing ▪ Enhance digester process optimization of process ▪ Boost biogas production ▪ Seek for energy reduction alternatives

3.3.2 Research Project Concepts in the "Energy Efficient Equipment" focus area

This section includes the potential project ideas developed by the participants within the "Energy Efficient Equipment" focus area in the New York and California workshops. Eight of the project ideas listed below were selected for potential funding opportunities and were considered part of the "List A" projects and "List B" introduced in Chapter 4. The project descriptions, research approach, and related budget and schedules of the projects selected are presented in Appendix D.

1. Making the case for micro-turbines

Hydropower is one of the least expensive energy generating options that water utilities are considering, as it plays an important role in stabilizing the electrical transmission grids and in meeting peak loads, reserve requirements and additional ancillary needs. New "microhydro" applications (low head dams or hydrodynamic propellers) have also been introduced on existing water storage or conveyance structures to provide up to 100 kW of electricity using natural water flows without the purchase of fuel.

The objective of this project is to investigate the application of micro-turbines in the water and wastewater industry and provide parameters related to sizing, parameters and life cycle assessments, etc.

2. Smart SCADA to help managers decide on what's useful in their facility (Maximize the use of the data)

Traditional SCADA systems have been great at collecting data from many different field devices and reporting data back to operators. However, traditional SCADA does not summarize or suggest operational changes to operators and managers to optimize system operation. Going forward, smart SCADA systems would provide an interface to tools that could suggest system changes and assist in decision making to optimize pumping. Examples of integration software may include pump scheduling software (e.g., Derceto), weather forecasting, proportional-integral-derivative (PID) optimization software, computerized maintenance management (CMMS) system, modeling, geographic information system (GIS) and laboratory information management system (LIMS), alarms and callout systems. The objectives of this project are to:

- Provide capability of SCADA assisted real time analysis of overall operational pumping efficiency and pump scheduling to reduce energy consumption and cost; and

- Demonstrate through pilots or case studies where the implementation of various tools could be used to compare pre and post savings in cost and usage quantities.

3. *Opportunities for minimizing leakage in a water system through the use of District Meter Areas (DMAs)*

AWWA estimates that about 20% of all potable water produced in the United States never reaches a customer water meter mostly due to loss in the distribution system. When water is lost through leakage, energy and water treatment chemicals are also lost. District Metered Areas can be used to cost effectively decrease some of the leakage losses by lowering distribution system pressures during times of low demand, typically at night. There has been limited use of DMAs in the U.S. to date. This project would remove a key barrier to implementation by providing a simple tool to estimate the costs and benefits of using DMAs for a specific utility.

The objective of this project is to produce a tool that individual utilities can use to estimate the costs and benefits of implementing DMAs to save energy, carbon, water, and chemicals.

4. *Integration of data management systems to facilitate effective process and maintenance decisions*

The objective of this project is to evaluate the integration of data management systems to facilitate effective process and maintenance decisions and develop predictive maintenance tools, improve the resilience of the facility, and provide a condition assessment of individual equipment and aboveground facilities (e.g., alignment, vibration thermal, oil testing, etc.).

5. *Assessment of mixing technologies to improve anaerobic digestion/biogas production optimization*

Anaerobic digestion at medium and large wastewater plants has been applied as an energy production and solids reduction tool. To achieve a successful digestion process it is important that tank mixing is performed properly and is of low energy consumption. The emergence of new mixing technologies and the existing mixing technologies need to be evaluated across different digesters over multiple years to determine their efficacy relative to maintaining a working digester volume (scum incorporation and grit deposition control) and producing a consistent volatile solids destruction and biogas production. The objectives of this project are to:

- Provide the wastewater industry decision makers with a performance based assessment of existing and emerging digester mixing technologies including mixing characteristics and energy consumption. Assessments will be tracked for multiple years in both pilot- and full-scale systems; and

- Develop a common process for evaluating new technologies relative to existing technologies.

6. *Performance benchmarking of pumps, motors and VFDs*

It is believed that much energy is wasted as a result of four factors: poor system design, poor equipment efficiency, poor operation and poor maintenance practices. Frequently utilities may be unaware of inefficient practices and this research will identify efficient practices and to address the above-referenced four factors. The objectives of this project are to:

- Identify the best wire-to-water efficiency possible in practice of a pumping system;
- Identify the best efficiency possible for the individual components, i.e. pumps, motors and VFDs; and
- Explore the efficiency of related equipment, such as transformers and motor starters, etc.

7. Next Generation Planning

The capital cost of equipment is not an accurate indicator of the life cycle cost of the equipment. Efficiency, equipment life (as warrantied or guaranteed), and maintenance costs can all contribute significantly to the overall life costs of a particular type of equipment. Efficiencies often equate to real reductions in chemical usage, energy, carbon footprint, and ultimately cost of the equipment.

The objective of this study is to provide a procurement framework/template for equipment selection criteria which includes capital cost, operational costs (i.e. energy and chemical usage), and maintenance costs of equipment, amortized over the life of the equipment to a single value. The operational cost development should include a significant focus on the determination of the actual anticipated operating conditions over the lifecycle being considered (e.g. average monthly operating condition over 30 years).

8. Tempering Your Energy Demands

The objective of this study is to evaluate emerging technologies that reduce the environmental impacts of maintaining equipment temperatures within their required operating ranges. The study should also investigate the geothermal sources coupled with HVAC and identify the energy savings by technology/uses and develop a balance between water and energy conservation.

9. Data to Business Intelligence

SCADA infrastructure is a standardized tool utilized throughout the water/wastewater industry that generates a considerable amount of operational data. However, this data is often collected in silos and is not consistently or effectively utilized, along with other available enterprise data sets, to inform equipment energy management decisions and guide preventive and corrective maintenance protocols. The objectives of this project are to:

- Enhance the use of advanced SCADA data to further inform decision making and establish a framework to improve the equipment life cycle; and
- Identify operational efficiencies, and establish energy/water efficiencies through an integrated data analytics approach.

10. Benchmarking – Setting the Standard

Establishing metrics is critical in evaluating system optimization, project feasibility and cost effectiveness. It enables governing authorities to make informed decisions, and allows for more accurate information to be used in public outreach messaging. The objectives of this project are to:

- Improve understanding of energy use and sources by water and wastewater process areas;
- Develop easy to understand energy management metrics and standardized economic evaluation protocol / tools for energy improvement projects.

11. Amp up Your System with Microturbines

Micro-turbines applications, as previously mentioned, have been introduced on existing water storage or conveyance structures as a greener alternative to traditional fuels. The objective of this project is to develop a framework on the economic feasibility of applying microturbines and to determine the available technologies, the criteria for head and flow conditions, proximity to demand, supporting infrastructure, and address redundancy and reliability concerns and life cycle costs.

12. Got Demand – Time of Use Metering

The objective of this project is to develop rate structures around time of use metering (i.e., electric utilities) and customer demand response programs and identify reduction of peak demand impact on infrastructure sizing. In addition, better capacity utilization/efficiency, revenue impacts and energy and water conservation impacts should be evaluated.

13. What you Measure Gets Done: Ammonia vs. Dissolved Oxygen Control

DO control is the current industry standard control strategy for improving aeration system efficiency. However, DO is really only a surrogate measurement with respect to effluent discharge constituents of concern (e.g., biological oxygen demand, ammonia, nitrate, etc.). Ammonia based aeration control provides the opportunity for a direct relationship between aeration system oxygen transfer and a primary oxic zone effluent discharge criteria. Research is needed to:

- Determine the potential for cost and energy savings benefits of using ammonia based aeration control compared to DO control across a broad range of activated sludge treatment processes (e.g., Modified Ludzack-Ettinger [MLE] configuration, A2O, oxidation ditch, 5-stage Bardenpho, step feed, etc.) and sizes (i.e., 1 to >100 MGD); and
- Understand the cost, energy, and associated environmental impact and reduction potential by using ammonia aeration control compared to DO control to achieve discharge effluent quality requirements.

3.3.3 Scoring Results of Research Project Concepts in the “Energy Efficient Equipment” focus area

The Energy Efficient Equipment breakout groups sorted the proposed project concepts into an order of importance, based on five criteria and the rating scale presented in Table 3.1. Table 3.5 presents the combined results of each group's ranking obtained from the two workshops.

Table 3.5 Scoring results of project concepts developed in the *Energy Efficient Equipment* focus area

Project	Scoring Criteria					Final Score[2]	Recommendations
	Likelihood of Implementation	**Timeliness**	**Economic Benefits**	**Environmental Benefits**	**Regulatory Risk Management[1]**		
Smart SCADA to help managers decide on what's useful in their facility (maximize the use of the data)	3	3	3	3	2	**14**	"List A" (based on NewYork workshop)
Assessment of mixing technologies to improve anaerobic digestion/biogas production optimization	3	3	3	3	2	**14**	"List B" (based on NewYork workshop)
Performance benchmarking of pumps, motors and VFDs	3	3	3	3	2	**14**	"List A" (based on NewYork workshop)
Opportunities for minimizing leakage in a water system through the use of District Meter Areas	2	3	3	3	2	**13**	"List B" (based on NewYork workshop)
Integration of data management systems to facilitate effective process and maintenance decisions	2	3	3	2	2	**12**	Project not selected
Making the case for micro-turbines	1	3	1	3	2	**10**	Project not selected
Next generation planning	3	2	3	2	-	**10**	"List A" (based on California workshop)
Data to business intelligence	2	2	3	2.5	-	**9.5**	"List A" (based on California workshop)
Benchmarking – Setting the standard	3	2	2	2	-	**9**	"List B" (based on California workshop)
What you measure gets done: Ammonia vs. DO control	3	2	2	2	-	**9**	"List B" (based on California workshop)
Got demand – Time of use metering	2	2	2	2	-	**8**	Project not selected
Tempering your energy demands	2	2	2	1	-	**7**	Project not selected

Amp up your system with microturbines	1	2	1	1	-	**5**	Project not selected

[1] Scoring criteria not considered during the California workshop.

[2] The total scores between the NY and the California workshops are not consistent and should not be compared based on the numerical value reported.

3.4 Energy Efficient Treatment Process Project Concepts

For the breakout discussion, the participants in the Energy Efficient Processes group were provided with some guidance on the topics to consider as a starting point for the discussion. The discussion topics included, but were not limited, to:

- Pre-treatment and source control to lower energy use;
- Energy efficient desalination processes (e.g., FO);
- Advanced membrane materials;
- Energy efficient disinfection processes (e.g., UV light emitting diodes);
- Energy efficient wastewater treatment processes;
- Main stream deammonification;
- Side-stream treatment;
- Energy efficient aeration;
- Optimization of treatment processes; and
- Sludge handling.

The outcomes of the breakout group discussions are summarized in the sections below.

3.4.1 Challenges and Opportunities in the "Energy Efficient Processes" area

During the first breakout session of the two workshops, the participants identified a number of challenges and trends that water and wastewater utilities are facing in relation to energy efficient processes. A number of these needs were used as input for the development of the research ideas during the second breakout group. Table 3.6 summarizes the topics and related discussion items that were covered during the first breakout discussions.

Table 3.6 Issues, challenges and opportunities highlighted in the "Energy Efficient Processes" focus area

Discussion Topic	Discussion Items
Disinfection	▪ Need further development of LED lamps for UV, particularly by working with manufacturers ▪ Identify impact on energy of United States EPA standards and monitoring requirements for disinfection of wastewater treatment ▪ Need to develop industry standards for microbial removal by various types of low pressure membranes
Desalination	▪ Develop a comprehensive database of novel membrane technologies ▪ Need optimization for membrane distillation (MD) processes to achieve high flux and minimal energy input ▪ Determine opportunities for colocation of power plants and desalination ▪ Determine reduction of energy use in RO for desalination

Discussion Topic	Discussion Items
	▪ Provide demonstrations for FO and research on draw solutions ▪ Study feasibility of closed loop power plant cooling
Pre-treatment	▪ Develop pre-treatment processes that reduce energy use at WWTPs ▪ Need source control to increase efficiency in drinking water treatment ▪ Investigate phosphorus and nitrogen trading ▪ Clarify use of wet weather blending ▪ Assist local environmental agencies in developing regulations for graywater and wastewater reuse ▪ Boost gray water recycling, direct use of stormwater, direct potable reuse
Sludge and Biosolids Handling	▪ Trucking of biosolids can be energy and GHG emission intensive ▪ Low emphasis is given on the energy aspect of solids in water/wastewater treatment ▪ Develop holistic optimization solution for solids-based processes ▪ Need optimization of traditional and innovative digestion processes ▪ Investigate feasibility of centralized biosolids handling sites for energy generation ▪ Investigate feasibility of digestion of primary sludge only for energy production ▪ Maximize solids as an asset (revenue generation or cost minimization approach) ▪ Investigate recuperative thickening ▪ Need to improve gravity thickening
Regulations	▪ Determine energy influence on regulatory development, particularly for trace contaminants, and impacts on costs ▪ Assess environmental benefits of regulations (e.g., shifting pollutant load from water to air) ▪ Increase receptiveness of net metering from the electric utility ▪ Review strategies for energy sale into the grid (especially for net positive plants)
Alternative/ Emerging Technologies	▪ Need to look at emerging technologies and assessing end water quality achieved and energy consumption ▪ Further development of genetically modified bacteria for nutrient removal ▪ Identify incentives for employing diffuser membranes ▪ Advances in technology on blowers ▪ OTE knowledge transfer to stakeholders for better commercialization of innovative aeration techniques ▪ Need to identify more efficient processes for waters with multiple constituents ▪ Identify alternatives to aeration for wastewater treatment ▪ Investigate feasibility of implementing deammonification at a larger scale and investigate aerobic granular sludge for energy savings for mainstream treatment ▪ Perform better nutrient and other resource recovery at the WWTP ▪ Develop side stream treatment to a greater extent (nutrient recovery) ▪ Improve optimization of primary treatment ▪ Identify opportunities to remove more solids through primary treatment, to increase gas production in digesters ▪ Need to investigate protocols and solutions for smart meters and sub-metering for system optimization
Aeration	▪ Identify air losses in channel mixing that prevent biomass settling ▪ Develop innovative methods of channel mixing to reduce energy losses ▪ Investigate the feasibility of heat capture from blowers ▪ Document case studies using high efficiency blowers

Discussion Topic	Discussion Items
	▪ Assess heat balance in digesters ▪ Identify the trade-offs between GHG production (energy needed for aeration) and removal of nutrients
Process optimization	▪ Lack of knowledge on energy efficient wastewater treatment processes ▪ Observed increase in energy demand with water recycling ▪ Need for optimization to reduce energy consumption, also in light of peak time of use ▪ Process optimization for energy reduction, i.e., in aeration system ▪ Reduce energy demand of specific system elements, i.e., aeration ▪ Need for case studies
Tools	▪ Need for better understanding on the applicability of pinch analysis for water treatment ▪ Determine the impact of energy cost on employing energy efficient processes ▪ Develop tools such pinch analysis (methodologies, equipment) to help with multi-contaminant waste stream with consideration of integration water and energy treatment optimization. ▪ Need for a decision support tool for treatment method applications

3.4.2 Research Project Concepts in the "Energy Efficient Processes" focus area

This section includes the potential project ideas developed by the participants within the "Energy Efficient Processes" focus area in the New York and California workshops. Eight of the project ideas listed below were selected for potential funding opportunities and were considered part of the "List A" projects and "List B" introduced in Chapter 4. The project descriptions, research approach, and related budget and schedules of the projects selected are presented in Appendix D.

1. Barriers to gray water reuse

Reusing gray water reduces the need for new fresh water sources and reduces reliance on groundwater resources. The objectives of this project are to:

- Evaluate water quality for a variety of sources of gray water;
- Assess regulatory issues for gray water use (i.e., plumbing codes, public health issues) and evaluate potential end users of the gray water resource and assess technologies to address regulatory constraints; and
- Perform a cost-benefit analysis of gray water use.

2. Assessment of selected microbial removal/inactivation in wastewater matrices by disinfection technologies

This project will evaluate the energy and carbon emissions of disinfection technologies on the inactivation of viruses. In addition the study will assess any byproduct formation due to technologies evaluated. Technologies in relation to dry and wet weather conditions will also be evaluated and technology combination for more efficacious disinfection will be evaluated.

3. Assessment of energy and GHGs in relation to innovative nutrient removal technologies

Reduction of nutrients in wastewater effluent has become and will remain a highly regulated goal. Many methods of nutrient reduction implemented in the last 20 years have not fully taken into account energy efficiency or GHG emissions. As more utilities are required to take into account GHG emissions, a comprehensive evaluation of GHG emissions due to individual nutrient removal technologies and techniques would allow utilities to make balanced decisions.

The objective of this project is to develop or promote implementation of nutrient removal technologies that decrease energy usage and reduce (or at a minimum do not increase) GHG emissions for wastewater treatment plants by: a) quantifying energy requirements and GHG emissions for various nutrient removal processes and b) developing guidelines for technology selection based on energy efficiency and GHG emissions.

4. Assessment of existing and future barriers to interconnecting and net-metering (gas and electric) of energy producers to the energy utility

The shift in resource recovery facilities from net-importers to net-zero and net-positive has created a need for beneficial use of excess energy (gas and electric). The energy utilities provide the most readily available market for this excess energy since facilities are already connected as consumers. However, the rules, regulations, and processes of interconnecting with the energy utilities as a supplier vary from state to state and utility to utility, as some are more receptive to renewable energy than others. The objectives of this project are to:

- Identify potential of interconnecting capacity nationwide, to evaluate the feasibility of selling excess gas/electricity from water and wastewater utilities and identify barriers to interconnectivity with utilities; and
- Evaluate case studies of successful net-metering/exporting projects should be evaluated.

5. Overcoming barriers to implementing biosolids energy recovery facilities

The objectives of this project are to:

- Evaluate small-scale modular biosolids energy recovery facility for small wastewater treatment facilities;
- Evaluate a regional approach to implementing biosolids energy recovery;
- Assess public-private partnerships (P3) opportunities and logistics in relation to biosolids and identify regulatory aspects and challenges.

6. Assess P3 opportunities and logistics in relation to water and wastewater energy projects

Funding sources for municipalities are becoming more limited. Utilities need to find new ways to fund and implement projects. Utilities and partners need new ways to diversify funding sources, allocate risks, and explore new revenue streams. Public-private partnerships or P3s, present an opportunity for utilities to fill in the gaps of their projects' funding. P3s present the opportunity for partnerships between the public and private sectors where projects can be funded with initial investments from the private sector with steady revenue streams being projected into the future. Research in this area is needed to:

- Provide information and guidance to water and wastewater utilities on these kinds of partnerships, so they may better understand the challenges, opportunities, characteristics and benefits of these agreements;
- Understand the barriers to such projects, including potential regulatory and political barriers, as well as to document lessons learned; and
- Understand the opportunities for such kinds of projects in the context of biosolids.

7. *Assessment of aeration technology for energy reduction and recovery*

Aeration is the largest consumer of energy at wastewater treatment plants. There are a number of opportunities for energy optimization for plants that have not recently upgraded their treatment process, as well as plants that have been upgraded. The objectives of this project are to:

- Perform a comprehensive review of energy efficiency practices in relation to aeration and to assess performance and reliability of existing and innovative technologies for energy consumption, GHG emissions and cost;
- Identify opportunities for heat energy recovery and reuse from air blowers;
- Provide guidance for operational optimization, instrumentation, and DO control;
- Provide guidance on alternative methods to control aeration costs by minimizing oxygen demand from organic and nitrogen loading; and
- Provide guidance to increase the efficiency of channel mixing, while maintaining/reducing associated energy consumption/costs.

8. *Comprehensive evaluation of energy consumption by current and innovative desalination technologies*

The objective of this project is to develop a comparison for energy efficient evaluations of a number of desalination technologies and determine appropriate metrics for evaluating the energy efficiencies of the technologies. In addition, the most appropriate water matrix for the application of the individual technologies should be also determined.

9. *Optimization of wastewater treatment processes to reduce energy consumption*

As treatment requirements increase and as energy consuming advanced technology is employed on a more widespread basis, energy demand is expected to likewise increase. Treatment processes tend to be optimized for treatment performance without regard for energy demand consequences. Few systems are sub-metered sufficiently to identify opportunities to decrease energy demands without treatment performance penalties. In addition, monitoring equipment is critical for process control. The objectives of this project are to:

- Identify opportunities to substantially reduce energy in process elements (e.g., aeration);
- Evaluate different system configurations for energy optimization and treatment performance;
- Evaluate monitoring equipment for process control; and
- Incorporate sub-metering for process energy reduction verification.

10. Development of ideal draw solution for energy efficient FO

A recently developed alternative to RO has been FO, which uses natural osmotic gradients to remove salt. RO has been characterized by high pressures and consequential energy needs, due to pumping to desalt high TDS waters. The principle involves providing a draw solution which is more concentrated than the liquid stream being treated, and then removing the draw solution from the permeate produced. Typical draw solutions involve inorganic materials such as ammonium carbonate, but others have been recently developed. A major issue that is prohibiting the more widespread use of the technology is the inability to effectively separate the draw solution from the permeate without adding energy for the process such as heat.

The objective of this study is to investigate, develop and assess alternative draw solutions for the FO process.

11. Develop an energy optimization decision tool for treatment of various constituents in drinking water sources

The objective of this project is to identify and contrast energy profiles of different treatment methods for various constituents and contaminants of concern and to identify energy differences between different treatment trains and configurations. An industry accepted computational protocol (and tool) for treatment process decision making should also be developed.

12. Develop standards for microbial removal by membrane technologies that are energy efficient in water recycling applications

The objective of this project is to benchmark existing installations to establish energy metrics and compare and contrast energy profiles of various methods to meet microbial standards for recycled water. In addition, the project will:

- Establish a realistic energy performance standard of the preferred treatment method; and
- Develop an approved protocol and standard by working closely with the health department or appropriate agencies.

13. Develop an holistic optimization solution for solids-based processes to maximize energy efficiency and production

To date, there has not been enough attention to the energy consumption and efficiency involved in solids digestion and dewatering. Further, the research conducted to date on solids management has resulted in only incremental improvements in the treatment and use of wastewater solids.

The objective of this study is to identify opportunities to reduce energy consumption in solids processing, significantly reduce solids and water content of biosolids, and maximize energy production from them.

14. Develop and evaluate energy efficient high flux membranes for membrane distillation

Membrane distillation, or MD, could be an attractive alternative to conventional desalination processes, especially if waste heat is available at "no" or "low" costs. The structure and chemistry of MD membranes are critical to achieve high performance of MD process in order to maximize the solvent vapor permeability while avoiding liquid solvent transport. A lot of progress has been made over the years to enhance MD membranes' performance. However, this process is still not widely applied at commercial scales due to inherit limitations of solvent vapor transport across the existing membranes. While much of MD is vendor driven, there is still a need to conduct the research to provide a more fundamental understanding of membrane materials and chemistry that would allow a more efficacious process.

The objective of this study is to develop and test suitable MD membranes with high flux which are energy efficient and cost effective.

3.4.3 Scoring Results of Research Project Concepts in the "Energy Efficient Processes" focus area

The Energy Efficient Processes breakout groups sorted the proposed project concepts into an order of importance, based on five criteria and the rating scale presented in Table 3.1. Table 3.7 presents the combined results of the individual group-based ranking obtained from the two workshops.

Table 3.7 Scoring results of project concepts developed in the *Energy Efficient Treatment Process* focus area

Project	Scoring Criteria					Final Score[2]	Recommendations
	Likelihood of Implementation	**Timeliness**	**Economic Benefits**	**Environmental Benefits**	**Regulatory Risk Management[1]**		
Assess P3 opportunities and logistics in relation to water and wastewater energy projects	3	3	3	3	2	**14**	"List A" (NewYork workshop)
Assessment of energy and GHGs in relation to innovative nutrient removal technologies	2	3	3	3	2	**13**	"List A" (NewYork workshop)
Assessment of aeration technology for energy reduction and recovery	3	2	3	3	2	**13**	"List B" (NewYork workshop)
Overcoming barriers to implementing biosolids energy recovery facilities	2	2	3	3	2	**12**	Project not selected
Optimization of wastewater treatment processes to reduce energy consumption	3	3	3	3	-	**12**	"List A" (California workshop)
Assessment of selected microbial removal/inactivation in wastewater matrices by disinfection technologies	3	3	1	1	3	**11**	Project not selected
Assessment of existing and future barriers to interconnecting and net-metering (gas and electric) of energy producers to the energy utility	1	3	3	3	1	**11**	"List B" (NewYork workshop)
Develop holistic optimization solution for solids-based processes to maximize energy efficiency and production	2	3	2	3	-	**10**	"List A" (California workshop)
Barriers to gray water reuse	1	2	3	2	1	**9**	Project not selected
Development of ideal draw solution for energy efficient forward osmosis	2	2	3	2	-	**9**	"List B" (California workshop)
Develop an energy optimization decision tool for treatment of various constituents in drinking water sources	2	3	2	2	-	**9**	Project not selected
Develop and evaluate energy efficient high flux membranes for membrane distillation	2	2	3	2	-	**9**	"List B" (California workshop)
Comprehensive evaluation of energy consumption by current and innovative desalination technologies	1	2	3	1	1	**8**	Project not selected
Develop standards for microbial removal by membrane technologies that are energy efficient in water recycling applications	2	2	1	1	-	**6**	Project not selected

[1] Scoring criteria not considered during the California workshop.

[2] The total scores between the NY and the California workshops are not consistent and should not be compared based on the numerical value reported.

3.5 Energy and Resource Recovery Project Concepts

For the breakout discussion, the participants in the Energy and Resources Recovery group were provided with some guidance on the topics to consider as a starting point for the discussion. The discussion topics included, but were not limited, to:

- Biogas recovery from biosolids and anaerobic treatment processes;
- Heat recovery;
- Conversion of waste to energy;
- Biofuel from algae;
- Microbial fuel cell;
- Nutrient recovery (ammonia and phosphorus recovery);
- Water reuse;
- Integrated resource recovery; and
- Tools and decision frameworks.

The outcomes of the breakout group discussions are summarized in the sections below.

3.5.1 Challenges and Opportunities in the "Energy and Resource Recovery" area

During the first breakout session of the two workshops, the participants identified a number of challenges and trends that water and wastewater utilities are facing in relation to energy and resource recovery. A number of these needs were used as input for the development of the research ideas during the second breakout group. Table 3.8 summarizes the topics and related discussion items that were covered during the first breakout discussions.

Table 3.8 Issues, challenges and opportunities highlighted in the "Energy and Resource Recovery" focus area

Discussion Topic	Discussion Items
Enhanced digestion	▪ Understand the impact of retention time ▪ Need to re-think digestion: higher temperature, small scale, decoupling HRTSRT ▪ Determine the environmental impacts (e.g., carbon footprint), also for biosolids transportation ▪ Develop better mixing systems ▪ Assess triple bottom line (TBL) and understand the implications on sustainability ▪ Investigate conditions of lower SRT and throughput ▪ Investigate pre-treatment and additives to improve sludge quality and quantity ▪ Investigate COD diversion strategies to digesters

Discussion Topic	Discussion Items
Co-digestion	▪ Understand consistent feedstock specifications ▪ Develop a decision matrix on feedstock alternatives ▪ Assess competition for feedstock and provide information on quality/quantity variations, full life cycle implications and transport considerations ▪ Understand the impact on dewatering and centrate quality ▪ Understand gas quality and cleaning, air quality, odor control ▪ Improve pre-treatment and screening technology ▪ Understand interconnections with electric utilities ▪ Determine impact on biosolid reuse ▪ Provide information on the regulatory framework for co-digestion (e.g., EPA Part 503 Biosolids Rule and beyond) ▪ Lack of end-user market definition ▪ Technological uncertainty and scale-up deficiencies ▪ Understand the economic sensitivity (ROI or other drivers such as energy, carbon, regulations)
Emerging technologies/ processes	▪ Lack of information on microbial cells (fuel, electrolysis, electrosynthesis, including inorganic (molten carbonate fuel cells [MCFC], phosphoric acid fuel cells [PAFC]) to produce hydrogen and higher hydrocarbons while aiding in water treatment) ▪ Need information on AnMBR in combination with novel technologies for energy recovery ▪ Further exploration of sub- and supercritical (gas and liquid fuel production) hydrothermal processes ▪ Need studies on the recovery of biochemical energy for bioplastics and biofuels using fermented feedstock materials (e.g., digested sludge, food wastes, etc.) ▪ Identify proven technologies that meet performance and economic targets ▪ Need for demonstration studies ▪ Need for detailed economic analyses
Integrated Resource Recovery	▪ Lack of information on the integration of co-digestion and enhanced digestion with struvite recovery ▪ Identify the appropriate path for an integrated resource recovery ▪ Inability to use reject water as a “recycle” stream to plants and need for assessment of regulatory limits, potential economic benefits and brine management ▪ Recovery of trace metals ▪ Water re-use quality ▪ Need collaboration with federal and state regulators (e.g. California Department of Public Health) on policy
Water reuse (IPR/DPR systems) conveyance energy reduction	▪ Need for an effective public outreach (education) ▪ Understand regulatory constraints ▪ Assess the environmental flow management ▪ Understand environmental buffers versus engineering buffer ▪ Collect case studies of successful demonstrations ▪ Develop roadmap for water utilities ▪ Achieve end-user buy-in
Energy generation and heat recovery	▪ Lack of studies on biogas and natural gas utilization, micro-turbines for electrical energy generation and waste heat recovery: optimization of heat utilization and proximity efficiencies, air quality management, maintenance (cost-effective gas clean-up), costs associated with blending gas sources (natural gas with biogas), energy efficiency metrics ▪ Lack of information on effluent heat capture and recovery: minimal temperature differentials, low temperature wastewaters, heat exchanger technology, physical access, proximity to end-use need, limitation to water source heat pump technology ▪ Need for increased sensitivity of mechanical prime mover ▪ Need for increased certainty in future regulations ▪ Identification of real market opportunities and develop partnerships

Discussion Topic	Discussion Items
Cost effective, proven technologies for broader spectrum of utility scopes (primarily for small utilities)	▪ Need understanding on the economies of scale ▪ Lack of required utility expertise ▪ Sensitivity to political pressure on rates ▪ Lack of access to adequate capital ▪ Isolation from broader energy management schemes and lack of awareness ▪ Lack of economic incentives due to "cheap" purchased power ▪ Need investigations on centralizing solids handling processes for small (<5 MGD; 50 kW) facilities for cost-effective energy management ▪ Investigation of small, low cost, low maintenance, proven, low emissions energy production
Decision tools for power	▪ Need for decision support tools for fuel source selection and management for electrical generation, types of electric motors. ▪ Need for techno-economic analyses for output products (e.g., heat recovery, higher hydrocarbon biofuels, natural gas, nutrients, renewables, etc.) ▪ Required highly specialized expertise and knowledge ▪ Uncertainty of future utility rates (e.g., natural gas) ▪ Uncertainty in markets and market proximity

3.5.2 Research Project Concepts

This section includes the potential project ideas developed by the participants within the "Energy and Resource Recovery" focus area in the New York and California workshops. Eight of the project ideas listed below were selected for potential funding opportunities and were considered part of the "List A" projects and "List B" introduced in Chapter 4. The project descriptions, research approach, and related budget and schedules of the projects selected are presented in Appendix D.

1. Mixing technology for anaerobic digestion and for High Strength Waste (HSW) storage

Digesters that take in HSW and other co-digested feedstocks operate at much higher solids content than conventional digesters. Many facilities faced with the decision of co-digesting HSW can accomplish this effectively with existing infrastructure if the anaerobic digester can be operated at substantially higher solids content. Conventional mixing equipment was not necessarily designed or tested to be effective at these higher solids concentrations. In addition, HSW storage tanks need to be mixed for a homogeneous feedstock and existing mixing technologies are not available to adequately perform this function due to waste characteristics and pH concerns. Mixing of HSW is further complicated since HSW storage tanks have limitations to utilization of existing mixing equipment due to structural issues.

The objective of this study is to evaluate new or repurposed technologies for robust, low-energy mixing within anaerobic digesters that treat high strength wastes, limits foaming, and also includes HSW storage tankage mixing for homogeneous feedstock.

2. Re-thinking digestion

Traditional digester technologies (single, and two stage-mesophilic digestion, thermophilic digestion, temperature-phased anaerobic digestion (TPAD), etc.) were developed for anaerobic digestion of municipal waste and/or separate, specific high-strength organic wastes (HSOW) with the goals of decreasing solids volumes, stabilizing sludge, producing biogas and meeting 503B regulations. With changes in the industry focusing on co-digestion of HSOW, there is a need to fundamentally reconsider how anaerobic digestion is designed, operated and controlled to recover high benefit products and account for new/changing feedstocks.

The objective of this study is to research new digestion processes aimed at achieving effective anaerobic digestion of HSOW, including co-digestion, to achieve a variety of specific energy and resource outcomes, even at small (< 5 MGD) Water Resource Recovery Facilities (treatment plants).

3. Digester Pre-treatment and Additives

The objective of this project is to further investigate ammonia uptake and microbial selection in digester processes at wastewater treatment plants and identify opportunities to improve gas quality and quantity, sludge dewaterability and FOG emulsification. The project will also perform triple bottom line evaluations of pre-treatment technologies should also be performed.

4. Feedstock quality and consistency

The development of specifications for acceptable feedstocks is important for decision making. An analytical tool should be developed to make on-site real time decisions and should be able to be adjusted for a specific plant's specifications.

The objectives of this project are to:

- Develop a protocol for characterization of feedstocks, create an analytical tool to determine whether feedstock specifications are met;
- Evaluate pre-treatment practices and technologies to optimize gas production; and
- Evaluate different feedstocks and their effect on dewaterability and identify/evaluate pre-treatment techniques and microbial selection to optimize ammonia uptake.

5. System-wide impact of codigestion

Co-digestion of various feedstocks at resource recovery facilities for the most part has been force fit into existing plants' designs and operations. There has been little thought given to the optimal operation and control for co-digestion on a whole system basis and on the impacts on digester operations (e.g., rheology, gas holdup, foaming, etc.), supernatant quality (e.g., nutrient concentrations), dewatering efficiency (e.g., polymer type, concentration and rate), and residuals quality (e.g., odors and pathogen regrowth). These impacts need to be better understood to determine technologies and operational practices required to optimize solids destruction, gas production and quality, and limit or improve downstream processes thereby improving energy efficiency, reducing energy costs and lowering GHG emissions.

The objective of this study is to determine optimal whole system design and implementation of co-digestion considering pretreatment options for source separated organics and other HSWs, mixing of storage tanks, integration of feedstocks into the digestion system, digester upsets, centrate quality, dewatering and residuals quality.

6. Chemical oxygen demand diversion to digesters

The objective of this project is to investigate the feasibility of COD diversion to digesters, the enhancement of biogas production and the reduction of costs for secondary treatment processes.

7. Regulatory framework for digestion of mixed feedstocks and residual beneficial use

The objective of this project is to determine regulatory or legislative changes required across multiple disciplines for both feedstock and biosolids reuse (e.g. water/solid waste/ agriculture/industrial) and to survey state policies for digestion of mixed feedstocks and residual beneficial use.

8. Cost-effective energy production & recovery strategies for smaller utilities: How can the smaller wastewater utility compete successfully in the energy arena and markets?

The objective of this project is to identify opportunities to reduce the footprint of anaerobic digestion (process intensification) and develop scaled-down, modularized elements, including sludge pretreatment technologies and alternative conversion technology (e.g., sub-critical). The project will also provide demonstrations of scale low-cost, low-emission power generation technologies.

9. Energy independence through optimization and beneficial end use of co-digestion feedstocks.

Co-digestion provides increased renewable energy production, reduced greenhouse gas emissions, and increased recycling rates. There are a number of potential co-digestion feedstocks including processed organic municipal solid waste; agricultural waste; fats, oils and grease; and food and beverage processing waste. The feedstock markets are dynamic, and utilities are often faced with the need to evaluate potential new feedstocks. The objectives of this study are to:

- Develop a database of existing co-digestion projects to include feedstock properties, technologies used, operation impacts, and biogas generation; and
- Develop a protocol that utilities can use to assess potential feedstocks in terms of energy value, operational concerns, and development of feedstock specifications.

10. Minimizing the energy footprint of water management.

Indirect potable reuse (IPR) and direct potable reuse (DPR) presents emerging water recycling alternatives, provides a new source of supply, and supports diversification of a utility's water supply portfolio. However, the process is still not widely accepted by local constituencies and needs more exposure/research to better position its use in the future. By developing more local water alternatives, IPR/DPR has the potential to reduce the overall energy footprint by general reduction of facilities such as shorter pipelines, reduced pumping, and related appurtenances. The objective of this study is to:

- Identify strategies to minimize the energy footprint of water management through the use of IPR/DPR; and
- Facilitate its acceptance to meet future water demands.

11. Producing energy, fuels, and chemical feedstocks from municipal wastewater using microbial cells.

Microbial electrochemistry has seen a surge of interest in recent years. However, while researchers have produced intriguing results in the lab, there are very few projects operating at a pilot scale. While microbial fuel cells, which produce electricity from organic feedstocks are the most widely known, there is a wide variety of electrical configurations (e.g., electrocatalytic, electrosynthetic) with the potential to produce hydrogen, methane, and higher hydrocarbons, which could serve either as fuels, or as precursors to the production of higher-value products. The objective of this project is to identify promising candidates among the array of microbial electrochemical candidates to produce energy, hydrogen, and higher hydrocarbons from municipal wastewater while simultaneously contributing to the efficacy of the treatment process.

12. Getting rid of the bubbles: What advances are needed to fully integrate AnMBR technology into municipal treatment systems?

The integration of anaerobic MBR technology into the mainstream secondary treatment process has potential to be one of the most significant step advances in the treatment industry. Market penetration potential of this technology into publicly-owned treatment facilities is high, as it has already seen advances in the industrial treatment in the United States and in municipal and industrial sectors in South America. Technical challenges remain that, to date, have limited its advance; challenges that require immediate research. These include final effluent quality, dissolved methane (resulting in GHG emissions), treatment efficacy of low organic-strength wastes, and biofouling of membrane surfaces. The objective of this study is to provide guidance to utilities to evaluate the advantage, disadvantages, and potential life cycle cost savings possible by converting from aerobic to anaerobic treatment of municipal wastewater.

3.5.3 Scoring Results of Research Project Concepts in the "Energy and Resources Recovery" focus area

The Energy and Resources Recovery breakout groups sorted the proposed research project concepts into an order of importance, based on five criteria and the rating scale presented in Table 3.1. Table 3.9 presents the combined results of the individual group-based ranking obtained from the two workshops.

Table 3.9 Scoring results of project concepts developed in the *Energy and Resource Recovery* focus area

Project	Scoring Criteria					Final Score[2]	Recommendations
	Likelihood of Implementation	**Timeliness**	**Economic Benefits**	**Environmental Benefits**	**Regulatory Risk Management[1]**		
Re-thinking digestion	3	3	3	3	3	**15**	”List A” (NewYork workshop)
Digester pre-treatment and additives	2.5	3	3	3	2.5	**14**	”List A” (NewYork workshop)
System-wide impact of co-digestion	3	3	2.5	2.5	3	**14**	”List B” (NewYork workshop)
Mixing technology for anaerobic digestion and for HSW storage	3	3	2	2	3	**13**	”List B” (NewYork workshop)
Getting rid of the bubbles: What advances are needed to fully integrate AnMBR technology into municipal treatment systems?	3	3	3	3	-	**12**	”List A” (California workshop)
COD diversion to digesters	2	2	2.5	2	2.5	**11**	Project not selected
Regulatory framework for digestion of mixed feedstocks and residual beneficial use	2	3	1	2	3	**11**	Project not ranked
Energy independence through optimization and beneficial end use of co-digestion feedstocks: How can the quantity, quality, availability, and variability of high organic strength wastes influence process performance (including biosolids quality) and whole plant impacts?	3	3	3	2	-	**11**	”List A” (California workshop)
Feedstock quality and consistency	3	3	1.5	1	1.5	**10**	Combined into previous research concept
Minimizing the energy footprint of water management: How can we emphasize conservation as part of the demand/supply solution?	2	3	2	2	-	**9**	”List B” (California workshop)
Producing energy, fuels, and chemical feedstocks from municipal wastewater using microbial cells.	3	1	2	2	-	**8**	”List B” (California workshop)
Cost-effective energy production & recovery strategies for smaller utilities: How can the smaller wastewater utility compete successfully in the energy arena and markets?	2	3	2	1	-	**8**	Project not ranked

[1] Scoring criteria not considered during the California workshop.

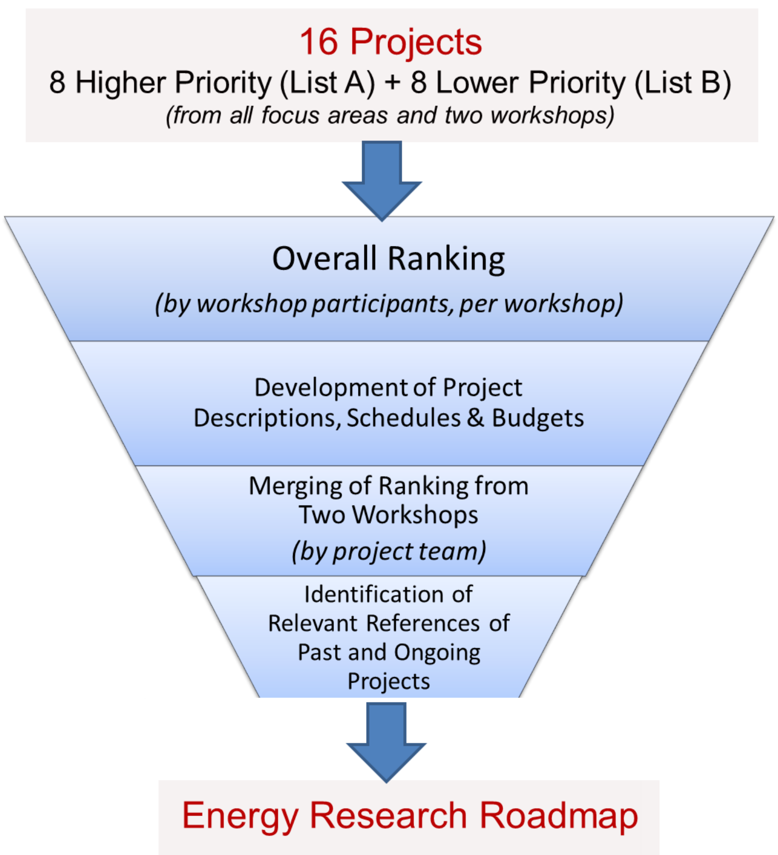
[2] The total scores between the NY and the California workshops are not consistent and should not be compared based on the numerical value reported.

CHAPTER 4 : Energy Research Prioritization and Roadmap Development

4.1 Project Prioritization

This chapter summarizes the approach used to prioritize the energy research project concepts developed and to synergize the outcomes of the two independent workshops. This chapter also presents the approach used to develop the energy research roadmap, the final outcome of this project. The approach used and discussed in this chapter is presented in Figure 4.1.

Figure 4.1 Approach used for the prioritization of energy research project concepts developed in New York and California workshops.



After projects were scored in each breakout session, all the participants met in a plenary session to have a general discussion on results and on the master lists of prioritized projects. First during the discussion, suggestions were made on the potential combination of projects with similar or complementary objectives and on additional goals that could potentially be integrated in the original project. These types of adjustments were needed to help fine-tune the high and lower priority lists. In each workshop, the workshop participants ranked the sixteen projects in a plenary session. Each participant could select only four projects from the “List A” and an additional four from the "List B" and prioritize them using a ranking scale from "1" to "4", with "4" being of highest importance to the participant and conversely "1" being of lowest importance. The resulting "List A" (Table 4.1 and Table 4.2) and "List B" list (Table 4.3 and Table 4.4) developed in the two workshops and the final relative ranking are presented below.

Table 4.1 Ranking of projects from "List A" identified in the New York workshop

ID	List A - Projects	Rank
NY-1	Compilation of best management practices for energy management	1
NY-2	Smart SCADA to help managers decide on what's useful in their facility (Maximize the use of the data)	2
NY-3	Rethinking anaerobic digestion for co-digestion and high-strength wastes to meet multiple beneficial outcomes	3
NY-4	Performance benchmarking of pumps, motors and VFDs	4
NY-5	Assess Public Private Partnership opportunities and logistics in relation to water and wastewater energy projects.	5
NY-6	Review of regulatory conflicts and recommendations for resolution	6
NY-7	Assessment of energy and GHGs in relation to innovative nutrient removal technologies	7
NY-8	Selection and pretreatment of feedstock, including waste activated sludge, primary sludge, and high strength waste	8

Table 4.2 Ranking of projects from "List A" identified in the California workshop

ID	List A - Projects	Rank
CA-1	Successful communication strategies for implementing energy management projects	1
CA-2	Universal data model for comparing pump performance	2
CA-3	SCADA: Data to business intelligence	3
CA-4	Lifecycle cost based equipment selection	4
CA-5	Development of tools for assessment of potential co-digestion feedstocks	5
CA-6	Optimization of wastewater treatment processes to reduce energy consumption	6
CA-7	Getting rid of the bubbles: What advances are needed to fully integrate AnMBR technology into municipal treatment systems?	7
CA-8	Develop holistic optimization solution for solids-based processes to maximize energy efficiency and production	8

Table 4.3 Ranking of projects from “List B” identified in the New York workshop

ID	List B - Projects	Rank
NY-9	Change management to address organizational barriers and promote/integrate energy efficiency	1
NY-10	Identifying and breaking down barriers to interconnecting and net-metering (gas and electric) of energy producers to the energy utility	2
NY-11	Guidance for wastewater utilities: best practices to reduce aeration energy consumption.	3
NY-12	Cost-benefit analysis of the application of SCADA and other data collection systems for energy management	4
NY-13	Mixing technology for anaerobic digestion and HSW storage	5
NY-14	System-wide impact of co-digestion	6
NY-15	Anaerobic digester mixing technology long-term assessment	7
NY-16	Opportunities to save energy, carbon, water and chemicals in a water system through the use of DMAs	8

Table 4.4 Ranking of projects from “List B” identified in the California workshop

ID	List B - Projects	Rank
CA-9	Balancing energy management and water quality	1
CA-10	Minimizing the energy footprint of water management	2
CA-11	Roadmap to a zero emission water utility	3
CA-12	Benchmarking – Setting the standard	4
CA-13	Producing energy, fuels, and chemical feedstocks from municipal wastewater using microbial cells	5
CA-14	What you measure gets done: The cost and energy benefits of ammonia vs. DO aeration control	6
CA-15	Development of ideal draw solution for energy efficient forward osmosis	7
CA-16	Develop and evaluate energy efficient high flux membranes for membrane distillation	8

Once projects were prioritized (Appendix C), the project descriptions were developed, as presented in Appendix D. The project descriptions include background and objectives of the project, the research approach, and the funding and resource allocation and lastly the benefits to the water and wastewater community.

4.2 Overall Research Roadmap

The thirty-two projects selected and ranked during the workshops were used to develop the energy research roadmap, designed to direct the future (5-10 years) research agenda for the WRF and the liaison agencies (NYSERDA and the Energy Commission). The individual project descriptions were developed as guidance for the release of future requests for proposals by these organizations.

Before the roadmap was developed, in order to merge the outcomes of the two workshops, the project team:

- Normalized the project scores. A total of 27 and 21 participants voted during the New York and California workshops, respectively. In order to merge the ranking of the two workshops, it was assumed that both workshops had the same number of participants. Thus, the scores of the projects identified during the New York workshop were normalized by 21, the number of participants to the California workshop;
- Combined the ranking based on the normalized scores. The combined ranking with normalized scores are presented in Appendix C;
- Identified projects with similar subject areas. The project team reviewed each project description and identified the potential overlaps (in objectives and outcomes) between projects that were developed by different groups in the two independent workshops. The project team also evaluated the temporal sequence (i.e., project dependence on the completion of the others) and the regional and geographical influence (east coast vs. west coast perspective); and
- Discussed among the team members and developed the overall roadmap.

After project re-prioritization, the energy research roadmap inclusive of the thirty-two projects was developed (Figure 4.2). The roadmap is composed by a total of 24 “stops” each representing a potential funding opportunity sorted by priority (from highest to lowest). “Stop 1” through “Stop 12” mostly includes projects with higher scores (List A), whereas “Stop 13” through “Stop 24” represents those that received lower scores by the participants (List B).

In five instances, the roadmap identifies opportunities to group or combine projects with similar objectives or expected outcomes regardless of their initial score. In consideration of the different focus, overall objectives and intents of the original projects, the description of these projects were not merged. Merging of these projects should be considered depending on funding availability and schedules.

The projects recommended for a potential merger include:

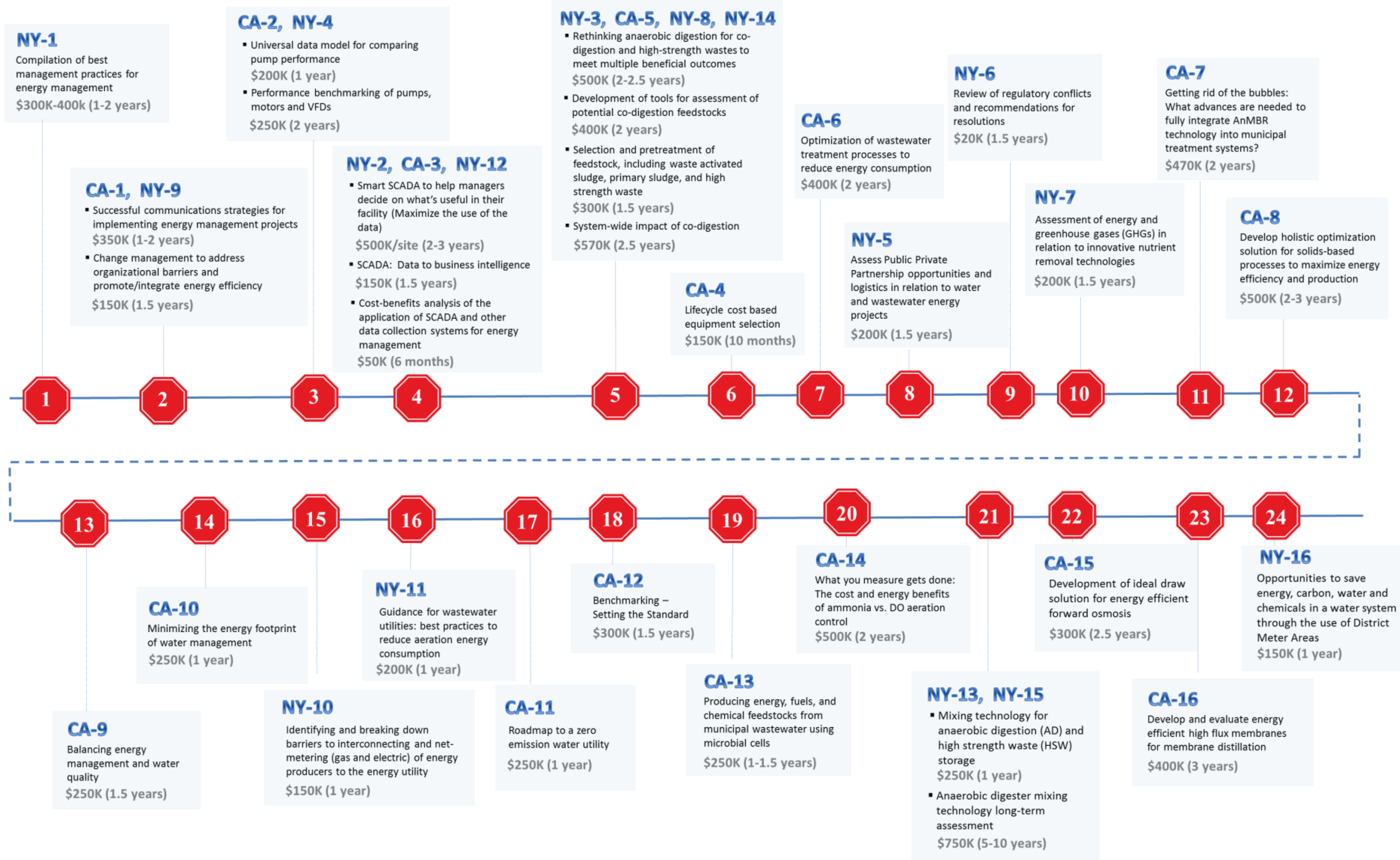
- ***CA-1 and NY-9.*** The “List A” project CA-1 on cultural issues and communications has similar objectives to those proposed in the “List B” project NY-9. Although their main focus is different, both projects claim the need for strategies that reduce internal organizational barriers to the implementation of energy programs and the need to complement the skill sets of operators with new trainings or certifications on energy management.

- ***NY-4 and CA-2***. Similarly, the projects NY-4 and CA-2 were considered high priority by the participants of the two independent workshops and they focus on benchmarking of pump performances from slightly different perspectives/ approaches. The model and database development proposed by the CA-2 project can be considered complimentary to the preliminary investigation on pump performance and benchmarking proposed by NY-4; thus, it is suggested that the findings of NY-4 will be available before issuing CA-2 requests-for-proposal.
- ***NY-2, CA-3, NY-12.*** Additional research on smart SCADA was requested by both workshops with high priority. Three projects on SCADA were developed and present potential for combination of similar objectives. The combined project can review the data collection options for water and wastewater utilities and related cost–benefit analysis of alternatives (NY-12), development of a framework and best practices for transforming operational data into maintenance strategies for utilities (CA-3) and pilot study of Smart SCADA alternatives (NY-2).
- ***NY-3, CA-5, NY-8, NY-14.*** Co-digestion is also one of the topics receiving great attention at the workshops. Four projects were developed around the need for feedstock characterization and specifications and related impacts on the anaerobic digestion process. Although similar objectives characterize these projects, their individual direction and focus appear to be different.
- ***NY-13 and NY-15***. Among the projects with low priority, the mixing of anaerobic digesters was found of importance with two projects developed in New York (NY-13 and NY-15), which have similar objectives related to the development of life cycle and performance assessment for conventional and emerging mixing technologies, however differ from the proposed duration of the assessment (short vs. long-term assessment).

It is recommended that before releasing a request-for-proposal, the agencies will consider the possibility to combine the suggested projects or delay the development of a project before the findings of those with similar objectives are published.

The identified projects represent estimated funding opportunities totaling approximately $9.8 million. These projects and the areas of research that they represent will enhance the implementation of energy programs and improve energy management in water and wastewater utilities.

Figure 4.2 Energy Research Roadmap



Note: Each project title is represented by the workshop location and the ranking of the project at that location (e.g., NY-2 is the second ranked project from the New York workshop)

In order to facilitate the preparation of requests for proposals for the projects, the project team identified key projects that can be used as a reference for some of the "stops" of the roadmap. Table 4.5 includes the complete list of these suggested references.

Table 4.5 Reference projects to be reviewed before releasing the RFPs

Project Code(s)	Reference Projects (Completed or forthcoming)
NY-1	Leiby and Burke, 2011; Brandt et al., 2010; Huxley et al., 2009; Jacobs et al., 2003; Arzbaecher et al., 2013; Cooper et al., 2011; Crawford, 2010b; Crawford, 2010a; EPA, 2008; Lekov, 2010.
CA-1, NY-9	Willis, forthcoming; Conrad, forthcoming; Lawson et al., 2013; Cantwell, 2010a.
CA-2, NY-4	Senon et al., forthcoming
NY-2, CA-3, NY-12	Badruzzaman et al., 2015; Wilcoxson and Badruzzaman, 2013; Jentgen et al., 2005; Jentgen et al., 2003.
NY-3, CA-5, NY-8, NY-14	Parry, 2014; Van Horne, forthcoming, Kilian, forthcoming
CA-4	He et al., 2013; Lorand, 2013; Monteith, 2011.
CA-6	Rosso, 2014; Tarallo, forthcoming; Chandran, forthcoming; Jimenez, forthcoming; Reardon, forthcoming; Tarallo, 2014
NY-5	Raucher et al., 2008; Cantwell, 2010b; Willis, forthcoming; Willis et al., 2012; Cooley and Wilkinson, 2012.
NY-7	Tarallo, forthcoming; Chandran, forthcoming; Jimenez, forthcoming; Tarallo, 2014.
CA-7	Salveson, 2013; Nikkel et al., 2013; Skerlos et al., 2013.
CA-8	Sandino, 2010; Monteith, 2008; Willis et al., 2012; Tarallo, forthcoming
NY-11	Rosso, 2014.
CA-11	Cooper et al., 2011; Leiby and Burke, 2011; Brandt et al., 2010; Lekov, 2010.
CA-12	Carlson and Walburger, 2007.
CA-13	Li, B., 2011.
CA-15	Cath et al., 2009; Adham, 2007.
CA-16	Wiesner, 2013.

CHAPTER 5 : Summary and Recommendations

Water and wastewater companies' investments in research and development have decreased in recent years and United States and United Kingdom government research and development schemes for the water sector are limited compared with those performed in the energy sector (Rothausen and Conway, 2011). There has been, however, an increasing awareness of the importance of energy management issues at water and wastewater utilities and the need for making better resource management and investment decisions.

In the last roadmap, developed in 2004, there has been a large focus on the optimization of treatment processes and introduction of innovative technologies for water and wastewater treatment. At least 25 of a total of 44 projects developed were related to water and wastewater treatment, including advanced oxidation, membrane processes, disinfection and pre-treatment alternatives. Substantial emphasis was given to energy generation (approximately 9 projects) from wastewater facilities (cleaning of digester gas, sludge pre-treatment). Approximately 8 projects were related to energy management, including energy tools or matrices development and understanding the balance between energy and water quality. Little to no emphasis was given to the following areas: water reuse, equipment (e.g., pumps, aerators), data management (SCADA).

Since 2004, research and technology have advanced and water and wastewater operations, including desalination and water reuse, have become more integrated. As such, previous roadmaps are outdated, do not include the latest developments in research and technology, and lack integrated research on water and wastewater operations and strategies. In order to create new research agendas and to structure new and innovative research questions that enable advancements in energy research for water and wastewater utilities, the WRF in liaison with the NYSERDA and the Energy Commission sponsored two workshops in New York and California in November 2014, to set the direction for future research. The workshops brought together approximately sixty experts from water and wastewater utilities, academics, industry, vendors/manufacturers, regulators, and research organizations to help develop the energy research roadmap for water and wastewater utilities. Unlike the previous roadmap developed in 2004, the discussion during the workshops was organized around four equally important general areas of research: energy management, energy efficient equipment, energy efficient processes, and energy and resource recovery. In each workshop, through two breakout sessions, the participants first addressed the issues and challenges faced under each focus area, and then identified a series of projects that could serve as solutions to the challenges identified.

A total of thirty-two projects were selected and prioritized by the workshop participants. Sixteen of these projects were considered of higher priorities than the others based on their likelihood of implementation at larger scale, timeliness of research needs, environmental and economic benefits. Major recommendations resulting from this project are:

- The energy research roadmap and the individual project descriptions that resulted from this study should be considered as guidance for the development of future requests for proposals by the WRF and the liaison-agencies. Prior to releasing the requests for proposals, the findings of the recently completed and on-going projects that were not available at the time of this study, as listed in Chapter 4, should be properly reviewed to avoid any potential duplication of research and to ensure that the future projects build on the past work.
- More collaboration among the research organizations and other entities (e.g., industry, governments, and regulatory organizations) should be encouraged in order to perform cooperative research and better leverage project funding. The published reports from each research organization should be shared with the others on a timely manner and the published reports should be advertised to the water/wastewater industry through a common platform (e.g., a joint energy research newsletter) so that the reports can be disseminated to a wider audience.
- Due to shifting priorities and the rapid development in research and technologies, it is recommended that the energy research roadmap is updated every five years. The workshop was valuable with respect to bringing together a group of experts that shared experiences on energy management practices and critically evaluate the focus of the future energy research for the water and wastewater industries. Thus, it is recommended that group of experts should be assembled more frequently (every 2 years), independently or in conjunction with other industry conferences, to discuss the results of completed and ongoing research projects.

GLOSSARY

AC	Alternating current
ACEEE	American Council for an Energy-Efficient Economy
AER	Advanced energy recovery
ANAMMOX	Anaerobic AMMonium Oxidation
AnMBR	Anaerobic membrane bioreactor
ASE	Alliance to Save Energy
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
AWS	Alliance for Water Stewardship
AWWA	American Water Works Association
AwwaRF	American Water Works Research Foundation
BEP	Best efficiency point
CAS	Conventional activated sludge (system)
CHEApet	Carbon heat energy assessment plant evaluation tool
CHP	Combined heat and power
CHP-SET	Combined heat and power system evaluation tool
CMMS	Computerized maintenance management system
COD	Chemical oxygen demand
CSIRO	Commonwealth Scientific and Research Organization
CWA	Clean Water Act
DEMON	DEamMONification
DMA	District-metered area
DMP	Demand management program
DO	Dissolved oxygen
DOE	United States Department of Energy
DPR	Direct portable reuse
DR	Demand response
DSS	Decision support system
EDR	Electrodialysis reversal
Energy Commission	California Energy Commission
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
EPWU	El Paso Water Utilities
ERD	Energy recovery device
ESAT	Environmental sustainability assessment tool
EWQMS	Energy and water quality management system
°F	Degrees Fahrenheit
FO	Forward osmosis
GAL	Gallon
gCO_2/MG	Grams of carbon dioxide per million gallons

GELCAT	Green energy life cycle assessment tool
GHG	Greenhouse gas
GIS	Geographic information system
GRI	Global Reporting Initiative
GWh	Gigawatt hour
GWRC	Global Water Research Coalition
HSOW	High strength organic waste
HSW	High strength waste
HRT	Hydraulic retention time
HVAC	Heating, ventilating, and air conditioning
IEC	Iowa Energy Center
IPR	Indirect portable reuse
ISD	Internal staging design
kWh	Kilowatt hour
kWh/kGal	Kilowatt hours per thousand gallons
kWh/m^3	Kilowatt hours per cubic meter
kWh/MG	Kilowatt hours per million gallons
LBNL	Lawrence Berkeley National Laboratory
LCAMER	Life cycle assessment manager for energy recovery
LED	Light-emitting diode
LEED	Leadership in Energy-Efficient Design
LIMS	Laboratory information management system
$Lm^{-2}h^{-1}$	Liters per square meter per hour
LCA	Life-cycle assessment
MABR	Membrane-aerated biofilm reactor
MassDEP	Massachusetts Department of Environmental Protection
MBR	Membrane bioreactor
MCFC	Molten carbonate fuel cells
MCRT	Mean cell retention time
MD	Membrane distillation
MED	Multi-effect distillation
MG	Million gallons
mg/L	Milligrams per liter
MGD	Million gallons per day
ML	Million liters
MLE	Modified Ludzack-Ettinger (process)
MSF	Multi-stage flash
MW	Megawatt
MWh	Megawatt hour
NGO	Nongovernmental organization
nm	Nanometer
NREL	National Renewable Energy Laboratory

NYCDEP	New York City Department of Environmental Protection
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and maintenance
ORP	Oxygen reduction potential
OTE	Oxygen transfer efficiency
P3	Public-private partnership
PAC	Project Advisory Committee
PAFC	Phosphoric acid fuel cells
PAO	Phosphate-accumulating organisms
PG&E	Pacific Gas and Electric Company
PID	Proportional-integral-derivative
PLC	Programmable logic controller
POTW	Publicly-owned treatment works
PSAT	Pump System Assessment Tool
PWE	Pressure or work exchanger
PWT	Pelton wheel turbine
R&D	Research and development
RD&D	Research, development, and demonstration
RO	Reverse osmosis
ROI	Return-on-investment
RPS	Renewable portfolio standard
RRTP	Reverse-running turbine pump
SCADA	Supervisory control and data acquisition
SDWA	Safe Drinking Water Act
SEM	Strategic energy management
SHARON	Single reactor system for high activity ammonium removal over nitrate
SRT	Solids retention time
SWRO	Seawater reverse osmosis
TBL	Triple bottom line
TDS	Total dissolved solids
TBL	Triple bottom line
TBP	Turbo-booster pump
TFN	Thin-film nanocomposite
TERRY	Tool for evaluating resource recovery
TN	Total nitrogen
TOU	Time-of-use
TPAD	Temperature-phased anaerobic digestion
UASB	Upflow anaerobic sludge blanket
UV	Ultraviolet
VC	Vacuum compression
VFD	Variable frequency drive
WECalc	Water-energy calculator

WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WEST	Water-energy sustainability tool
WRF	Water Research Foundation
WWTP	Wastewater treatment plant

REFERENCES

ACEEE (American Council for an Energy Efficient Economy). 2005. *A Roadmap to Energy in Water and Wastewater Industry*. Report # IE054.

Adham, S. 2007. *Dewatering Reverse Osmosis Concentrate from Water Reuse Applications Using Forward Osmosis.* Water Reuse Research Foundation. WRRF # 05-009-1.

Arzbaecher, C., K. Parmenter, R. Ehrhard, and J. Murphy. 2013. *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*. Denver, Colo.: Water Research Foundation; Palo Alto, Calif.: Electric Power Research Institute.

AWE (Alliance for Water Efficiency) and ACEEE (American Council for an Energy Efficient Economy). 2013. *Water Energy nexus research recommendations for future opportunities.* June, 2013.

Badruzzaman, M., C. Cherchi, J. Oppenheimer, C.M. Bros, S. Bunn, M. Gordon, V. Pencheva, C. Jay, I. Darcazallie, and J.G. Jacangelo. 2015. *Optimization of Energy and Water Quality Management Systems for Drinking Water Utilities*. Denver, Colo.: Water Research Foundation, forthcoming.

Bollaci, D. 2013. *Challenge Projects on Low Energy Treatment Schemes for Water Reuse, Phase 1.* Water Environment Research Foundation

Boulos, P.F. and C.M. Bros. 2010. *Assessing the carbon footprint of water supply and distribution systems*. Journal of American Water Works Association, 102 (11).

Brandt, M.J., R.A. Middleton, and S. Wang. 2010. *Energy Efficiency in the Water Industry: A compendium of Best Practices and Case studies*. UK Water Industry Research. WERF #OWSO9C09.

Bunn, S. 2011. Optimizing operations holistically for maximum savings, Proceedings of Annual Conference and Exposition 2010 of the American Water Works Association, June 20–24, 2010, Chicago, IL.

Burn, S., T. Muster, A. Kaksonen, and G. Tjandraatmadja. 2014. *Resource Recovery from Wastewater: A Research Agenda*. Water Environment Research Foundation. Report *#NTRY2C13.*

Cantwell, J.L. 2010a. *Energy Efficiency in Value Engineering: Barriers and Pathways.* Water Environment Research Foundation. WERF # OWSO6R07a.

Cantwell, J.L. 2010b. *Overview of State Energy Reduction Programs and Guidelines for the Wastewater Sector.* Water Environment Research Foundation. WERF # OWSO6R07b.

Carlson, S.W., and A. Walburger. 2007. *Energy Index Development for Benchmarking Water and Wastewater Utilities.* Denver, Colo.: Water Research Foundation.

Cath, T.Y., J.E. Drewes, and C.D. Lundin. 2009. *A Novel Hybrid Forward Osmosis Process for Drinking Water Augmentation using Impaired Water and Saline Water Sources.* Las Cruces, NM: WERC; Denver, Colo.: Water Research Foundation.

Chan, C. 2013. Personal communication. Interview on June 6th, 2013. East Bay Municipal Utility District, Oakland, CA.

Chandran, K. [N.d.] *Development and Implementation of a Process Technology Toolbox for Sustainable Biological Nutrient Removal using Mainstream Deammonification.* Water Environment Research Foundation. WERF # STAR_N2R14. Forthcoming.

Chang, Y., D.J. Reardon, P. Kwan, G. Boyd, J. Brandt, K.L. Rakness, and D. Furukawa. 2008. *Evaluation of Dynamic Energy Consumption of Advanced Water and Wastewater Treatment Tecnologies.* Denver, Colo.: Water Research Foundation.

Chaudhry, S., and C. Shrier. 2010. *Energy sustainability in the water sector: Challenges and opportunities*. Proceedings of Annual Conference and Exposition 2010 of the American Water Works Association, June 20–24, 2010, Chicago, IL.

Cherchi, C., M. Badruzzaman, J. Oppenheimer, C.M. Bros, and J.G. Jacangelo. 2015. Energy and water quality management systems for water utility's operations: A review. Journal of environmental management, 153, 108-120.

Conrad, S. [N.d.]. *Water and Electric Utility Integrated Planning.* Denver, Colo.: Water Research Foundation. Forthcoming.

Conrad, S.A., J. Geisenhoff, T. Brueck, M. Volna, and P. Brink. 2011. *Decision Support System for Sustainable Energy Management.* Denver, Colo.: Water Research Foundation.

Cooley, H., and R. Wilkinson. 2012. *Implications of Future Water Supply Sources for Energy Demands.* Water Reuse Research Foundation. WRRF # 08-16.

Cooper, A., C. Coronella, R. Humphries, A. Kaldate, M. Keleman, S. Kelly, N. Nelson, K. O'Connor, S. Pekarek, J. Smith, and Y. Zuo. 2011. *Energy Production and Efficiency Research – The Roadmap to Net-Zero Energy*. Water Environment Research Foundation Fact Sheet, 2011.

Crawford, G.V. 2011a. *Sustainable Energy Optimization Tool- Carbon Heat Energy Assessment Plant Evaluation Tool (CHEApet)*. Water Environment Research Foundation. Report # OWSO4R07c.

Crawford, G.V. 2011b. *Demonstration of the Carbon Heat Energy Assessment Plant Evaluation Tool (CHEApet)*. Water Environment Research Foundation. Report # OWSO4R07g.

Crawford, G.V. 2010a. *Best Practices for Sustainable Wastewater Treatment: Initial Case Study Incorporating European Experience and Evaluation Tool Concept*. Water Environment Research Foundation. Report # OWSO4R07a.

Crawford, G.V. 2010b. *Technology Roadmap for Sustainable Wastewater Treatment Plants in a Carbon-Constrained World*. Water Environment Research Foundation. Report # OWSO4R07d.

Crawford, G., and J. Sandino. 2010. Energy Efficiency in Wastewater Treatment in North America. WERF, Alexandria, VA.

CRS (Congressional Research Service). 2014. *Energy-Water Nexus: The Water Sector's Energy Use*. A Report.

Elimelech, M., and W.A. Phillip. 2011. *The future of seawater desalination: Energy, technology, and the Environment*. Science, 333, 712 – 717.

El-Shafai, S.A., F.A. El-Gohary, F.A. Nasr, N. Peter van der Steen, and H.J. Gijzen. 2007. *Nutrient recovery from domestic wastewater using a UASB-duckweed ponds system*. Bioresource Technology 98, 798-807.

Environmental KTN (Environmental Knowledge Transfer Network). 2008. *Energy Efficient Water & Wastewater Treatment. Stimulating business innovation and environmental protection through the transfer of knowledge*. January, 2008.

EPA (U.S. Environmental Protection Agency). 2004. *Guidelines for Water Reuse.* September, 2004.

EPA (U.S. Environmental Protection Agency). 2008. *Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities.*

EPA (U.S. Environmental Protection Agency). 2012a. *Centers for Water Research on National Priorities Related to a Systems View of Nutrient Management*. Solicitation # US EPA-G2012-STAR-H1.

EPA (U.S. Environmental Protection Agency). 2012b. *National Water Program 2012 Strategy: Response to Climate Change*. December 2012.

Forrest, A.L., K.P. Fattah, D.S. Mavinic, and F.A. Koch. 2008. *Optimizing struvite production for phosphate recovery in WWTP*. Journal of Environmental Engineering, 134(5), 395-402.

Ghiu, S. 2014. *DORIS – Energy Consumption Calculator for Seawater Reverse Osmosis Systems*. Denver, Colo.: Water Research Foundation.

Griffiths-Sattenspiel, B., and W. Wilson. 2009. *The carbon footprint of water*. River Network, Portland.

GWRC (Global Water Research Coalition). 2008. *Water and energy: Report of the GWRC Research Strategy workshop.*

He, C., Z. Liu, and M. Hodgins. 2013. *Using Life Cycle Assessment for Quantifying Embedded Water and Energy in a Water Treatment System*. Water Research Foundation. WRF #4443.

Hernández, E., M.A. Pardo, E. Cabrera, and R. Cobacho. 2010. *Energy assessment of water networks, a case study*, Proceedings of the Water Distribution System Analysis 2010 Conference – WDSA2010, Tucson, AZ, USA, Sept. 12–15, 2010.

Hightower, M., D. Reible, and M. Webber. 2013. *Workshop Report: Developing a Research Agenda for the Energy Water Nexus.* National Science Foundation. Grant # CBET 1341032.

Holt, J.K., H.G. Park, Y.M. Wang, M. Stadermann, A.B. Artyukhin, C.P. Grigoropoulos, A. Noy, and O. Bakajin. 2006. *Fast mass transport through sub-2-nanometer carbon nanotubes.* Science, 312, 1034 – 1037.

Horne, J., and A. Kricun. 2008. *Using management systems to reduce energy consumption and energy costs.* Proceedings of the *Water Environment Federation,* 2008(10), 5826-5843.

Horne, J., J. Turgeon, and E. Byous. 2011. Energy Self-Assessment Tools and Energy Audits for Water and Wastewater Utilities. A presentation.

Horvath, A., and J. Stokes. 2013. *Life-cycle energy assessment of alternative water supply systems in California.* California Energy Commission. Report # CEC-500-2013-037.

House, L. 2007. *Water supply-related electricity demand in California*. California Energy Commission. Report # CEC-500-2007-114.

House, L. 2011. *Time-of-use water meter effects on customer water use*. California Energy Commission. Report # CEC-500-2011-023.

Huxley, D.E., W.D. Bellamy, P. Sathyanarayan, M. Ridens, and J. Mack. 2009. *Greenhouse Gas Emission Inventory and Management Strategy Guidelines for Water Utilities*. Denver, Colo.: Water Research Foundation.

Innovyze, Inc. 2013. Available online at: www.innovyze.com

Jacangelo, J., A. Subramani, J. Oppenheimer, M. Badruzzaman. 2013. *Renewable Energy Technologies and Energy Efficiency Strategies (Guidebook for Desalination and Water Reuse).* Water Reuse Research Foundation. WateReuse-08-13.

Jacobs, J., T.A. Kerestes, and W.F. Riddle. 2003. *Best Practices for Energy Management.* Denver, Colo.: AwwaRF.

Jentgen, L.A., S. Conrad, H. Kidder, M. Barnett, T. Lee, and J. Woolschlager. 2005. *Optimizing Operations at JEA's Water System*. Denver, Colo.: AwwaRF.

Jentgen, L.A., S. Conrad, R. Riddle, E.V. Sacken, K. Stone, W. Grayman, and S. Ranade. 2003. *Implementing a Prototype energy and Water Quality Management System*. Denver, Colo.: AwwaRF.

Jimenez, J. [N.d.]. *Advancing Anaerobic Wastewater and Solids Treatment Processes.* Water Environment Research Foundation. WERF # ENER5R12. Forthcoming.

Johnson Foundation. 2013. *Building Resilient Utilities How Water and Electric Utilities Can Co-Create Their Futures*. Report.

Jolly, M., and J. Gillard. 2009. *The economics of advanced digestion*. In Proceedings of the 14th European Biosolids and Organic Resources Conference and Exhibition—9th–11th November (Vol. 2009).

Kärkkäinen, S., and J. Ikäheimo. 2009. *Integration of demand side management with variable output DG.* Proceedings of the 10th IAEE European conference, September, 2009, Vienna, 7–10.

Kang, S.J., K.P. Olmstead, and T. Allbaugh. 2010. *A Roadmap to Energy Self-Sufficiency for U.S. Wastewater Treatment Plants*. In the Proceedings of the Water Environment Federation Technical Exhibition and Conference (WEFTEC), 2010.

Kenway, S.J., A. Priestley, S. Cook, S. Seo, M. Inman, A. Gregory, and M. Hall. 2008. *Energy Use in the Provision and Consumption of Urban Water in Australia and New Zealand.* Commonwealth Scientific and Industrial Research Organisation, Victoria, Australia; & Water Services Association of Australia, Melbourne, Australia. Available online at: www.clw.csiro.au/publications/waterforahealthycountry/2008/wfhc-urban-water-energy.pdf.

Kilian, R.E. [N.d.]. *Co-digestion of Organic Waste – Addressing Operational Side Effects.* Water Environment Research Foundation. WERF # ENER9C13. Forthcoming.

Kim, Y.J., and J.H. Choi. 2010. *Enhanced desalination efficiency in capacitive deionization with an ion-selective membrane*. Separation and Purification Technology, 71, 70 – 75.

Knapp, J., and G. MacDonald. [N.d.] "Energy Recovery from Pressure Reducing Valve Stations Using In-Line Hydrokinetic Turbines." Denver, Colo.: Water Research Foundation. Forthcoming.

Latimer, R. 2014. *Towards a renewable future: assessing resource recovery as a viable treatment alternative*. Water Environment Research Foundation. Report #NTRY1R12.

Lawson, R., R. Sandra, G. Shreeve, and A. Tucker. 2013. *Links and Benefits of Water and Energy Efficiency Joint Learning.* Denver, Colo.: Water Research Foundation.

Leiby, V., and M.E. Burke. 2011. *Energy Efficiency in the North American Water Supply Industry: A Compendium of Best Practices and Case Studies.* Denver, Colo.: Water Research Foundation.

Lekov, A. 2010. *Opportunities for Energy Efficiency and Open Automated Demand Response in Wastewater Treatment Facilities in California* - Phase I Report. A Report by the Lawrence Berkeley National Laboratory.

Li, B. 2011. *Electricity Generation from Anaerobic Wastewater Treatment in Microbial Fuel Cell.* Water Environment Research Foundation. WERF # OWSO8C09.

Liner, B., and C. Stacklin. 2013. Driving Water and Wastewater Utilities to More Sustainable Energy Management. ASME 2013 Power Conference. American Society of Mechanical Engineers, 2013.

Lisk, B., E. Greenberg, and F. Bloetscher. 2013. *Case Studies: Implementing Renewable Energy at Water Utilities.* Denver, Colo.: Water Research Foundation.

Lorand, R.T. 2013. *Green Energy Life Cycle Assessment Tool Version 2*. Denver, Colo.: Water Research Foundation.

Maurer, M., P. Schwegler, and T.A. Larsen. 2003. Nutrients in urine: energetic aspects of removal and recovery. Water Science & Technology, 48(1), 37-46.

McCarty, P.L., J. Bae, and J. Kim. 2011. *Domestic wastewater treatment as a net energy producer–can this be achieved?* Environmental science & technology, 45(17), 7100-7106.

McCutcheon, J., R.L. McGinnis, and M. Elimelech. 2005. *A novel ammonia-carbon dioxide forward (direct) osmosis desalination process*. Desalination, 174, 1 – 11.

McGuckin, R., J. Oppenheimer, M. Badruzzaman, A. Contreras, and J.G. Jacangelo. 2013. *Toolbox for Water Utility Energy and Greenhouse Gas Emission Management: An International Review*. Denver, Colo.: Water Research Foundation.

Means, E. 2004. *Water and Wastewater Industry Energy Efficiency: A Research Roadmap*. Denver, Colo.: AwwaRF.

Mo, W., and Q. Zhang. 2013. *Energy–nutrients–water nexus: Integrated resource recovery in municipal wastewater treatment plants*. Journal of environmental management, 127, 255-267.

Monteith, H.D. 2008. *State-of-the-Science Energy and Resource Recovery from Sludge.* Water Environment Research Foundation. WERF # OWSO3R07.

Monteith, H.D. 2011. *Life Cycle Assessment Manager for Energy Recovery (LCAMER)*. Water Environment Research Foundation. Report # OWSO4R07h/f.

MWH Global. 2007. *Assessment of Energy Recovery Devices for Seawater Desalination" by MWH Global, 2007 – West Basin Ocean Water Desalination Demonstration Facility*, Redondo Beach, CA.

MWH Global. 2014. *The burning question on energy recovery*. February 2014. Available at: wwtonline.co.uk.

Nerenberg, R., J. Boltz, G. Pizzarro, M. Aybar, K. Martin, and L. Downing. 2013. *Challenge Projects on Low Energy Treatment Schemes for Water Reuse, Phase 1.* Water Reuse Research Foundation. WateReuse-10-06C, University of Notre Dame.

Nikkel, C., E. Marchand, A. Achilli, and A. Childress. 2013. *Challenge Projects on Low Energy Treatment Schemes for Water Reuse, Phase 1.* Water Reuse Research Foundation WateReuse-10-06B, University of Nevada, Reno.

NYSERDA (New York State Energy Research and Development Authority). 2004. *Energy Efficiency in Municipal Wastewater Treatment Plants: Technology Assessment.* NYSERDA. Albany, N.Y.

NYSERDA (New York State Energy Research and Development Authority). 2008a. *Statewide Assessment of Energy Use by the Municipal Water and Wastewater Sector. NYSERDA. Albany, N.Y.*

NYSERDA (New York State Energy Research and Development Authority). 2008b. *Energy and the Municipal Water and Wastewater Treatment Sector.* A presentation for the Genesee/Finger Lakes Regional Planning Council. May 9, 2008.

NYSERDA (New York State Energy Research and Development Authority). 2010. *Water & wastewater energy management best practices handbook.* NYSERDA. Available online at: *http://www.nyserda.ny.gov.*

Papa, F., D. Radulj, B. Karney, and M. Robertson. 2013. *Pump Energy Efficiency Field Testing & Benchmarking in Canada.* International Conference on Asset Management for Enhancing Energy Efficiency in Water and Wastewater Systems, International Water Association, Marbella, Spain.

Parry, D.L. 2014. *Co-digestion of Organic Waste Products with Wastewater Solids: Final Report with Economic Model.* Water Environment Research Foundation. WERF # OWSO5R07.

PLMA (Peak Load Management Alliance). 2002. *Demand Response: Principles for regulatory guidance*. Jupiter, Fla.: Peak Load Management Alliance, Report.

Rajagopalan, G. 2014. *The use of novel nanoscale materials for sludge dewatering*. California Energy Commission. Report # CEC-500-2014-081.

Raucher, R.S., J.E. Cromwell, K. Cooney, P. Thompson, L. Sullivan, B. Carrico, and M. MacPhee. 2008. *Risks and Benefits of Energy Management for Drinking Water Utilities.* Denver, Colo.: AwwaRF.

Reardon, D. [N.d.] *Striking the Balance between Nutrient removal in Wastewater Treatment and Sustainability.* Water Environment Research Foundation. WERF # NUTR1R06n. Forthcoming.

Rosso, D. 2014. *Framework for Energy Neutral Treatment for the 21st Century through Energy Efficient Aeration.* Water Environment Research Foundation. WERF # INFR2R12.

Rosso, D., L.E. Larson, and M.K. Stenstrom. 2010a. *Aeration of large-scale municipal wastewater treatment plants: state of the art*. CEC-500-2009-076-APF.

Rosso, D., S.-Y. Leu, P. Jiang, L.E. Larson, R. Sung, and M.K. Stenstrom. 2010b. *Aeration Efficiency Monitoring with Real-Time Off-Gas Analysis*. CEC-500-2009-076-APF.

Rosso, D., and G. Rajagopalan. 2013. *Energy reduction in membrane filtration process through optimization of nanosuspended particle removal.* California Energy Commission. Report # CEC-500-2013-132.

Rothausen, S.G., and D. Conway. 2011. Greenhouse-gas emissions from energy use in the water sector. Nature Climate Change, 1(4), 210-219.

Salveson, A.T. 2013. *Challenge Projects on Low Energy Treatment Schemes for Water Reuse, Phase 1.* Water Reuse Research Foundation. WateReuse-10-06A, Carollo Engineers.

Salveson, A. [N.d.] *Evaluation of Innovative Reflectance Based UV for Enhanced Disinfection and Advanced Oxidation*. Denver, Colo.: Water Research Foundation. Forthcoming.

Sanders, K.T., and M.E. Webber. 2012. *Evaluating the energy consumed for water use in the United States*. Environmental Research Letters, 7(3), 034034.

Sandino, J. 2010. *Evaluation of Processes to Reduce Activated Sludge Solids Generation and Disposal.* Water Environment Research Foundation. WERF # 05-CTS-3.

Seacord, T., J. MacHarg, and S. Coker. (2006). *Affordable Desalination Collaboration 2005 Results*. Proceedings of the American Membrane Technology Association Conference in Stuart, FL, USA, July 2006.

Semiat, R. 2008. *Energy issues in desalination processes*. Environmental Science and Technology, 42, 8193 – 8201.

Senon, C., M. Badruzzaman, A. Contreras, J. Adidjaja, M.S. Allen, and J.G. Jacangelo. [N.d.] *Drinking Water Pump Station Design and Operation for Energy Efficiency*. Denver, Colo.: Water Research Foundation. Forthcoming.

Skeens, B., W. Wood, and N. Spivey. 2009. *Water production and distribution real–time energy management.* Proceedings of the Awwa DSS Conference, Reno, NV, USA, September.

Skerlos, S.J., L. Raskin, N.G. Love, A.L. Smith, L.B. Stadler, and L. Cao. 2013. *Challenge Projects on Low Energy Treatment Schemes for Water Reuse, Phase 1.* Water Reuse Research Foundation. WateReuse-10-06D, University of Michigan.

Spellman, F.R. 2013. *Water & Wastewater Infrastructure: Energy Efficiency and Sustainability*. CRC Press, Boca Raton, FL.

Stillwell, A.S., D.C. Hoppock, and M.E. Webber. 2010. *Energy recovery from wastewater treatment plants in the United States: a case study of the energy-water nexus." Sustainability,* 2.4 (2010): 945-962.

Stover, R. 2007. *Seawater reverse osmosis with isobaric energy recovery devices*. Desalination, 203, 168 – 175.

Stover, R., and N. Efraty 2011. *Record low energy consumption with Closed Circuit Desalination*. International Desalination Association (IDA) World Congress – Perth Convention and Exhibition Center (PCEC), Perth, Western Australia, September 4 – 9, 2011.

Subramani, A., M. Badruzzaman, J. Oppenheimer, and J.G. Jacangelo. 2011. *Energy minimization strategies and renewable energy utilization for desalination: A review*. Water Research, 45, 1907 – 1920.

Sui, H., B.G. Han, J.K. Lee, P. Walian, and B.K. Jap. 2001. *Structural basis of water specific transport through the AQP1 water channel*. Nature, 414, 872 – 878.

Tarallo, S. 2014. *Utilities of the Future Energy Findings.* Water Environment Research Foundation. WERF # ENER6C13.

Tarallo, S. [N.d.] *Energy Balance and Reduction Opportunities, Case Studies of Energy-Neutral Wastewater Facilities and Triple Bottom Line (TBL) Research Planning Support*. Water Environment Research Foundation. WERF # ENER1C12. Forthcoming.

Thompson, L., K. Song, A. Lekov, and A. McKane. 2008. A*utomated Demand Response Opportunities in Wastewater Treatment Facilities*. Ernest Orlando Lawrence Berkeley National Laboratory. November 2008.

Toffey, B. 2010. *Beyond Zero Net Energy: Case Studies of Wastewater Treatment for Energy and Resource Production*. AWRA-PMAS Meeting. September 16, 2010.

Van Horne, M. [N.d.] *Developing Solutions to Operational Side Effects Associated with Co-digestion of High Strength Organic Wastes.* Water Environment Research Foundation. WERF # ENER8R13. Forthcoming.

Van Paassen, J., W. Van der Meer, and J. Post. 2005. *Optiflux: from innovation to realization*. Desalination 178, 325-331.

Veerapaneni, S., B. Jordan, G. Leitner, S. Freeman, and J. Madhavan. 2005. *Optimization of RO desalination process energy consumption*. International Desalination Association World Congress, Singapore.

Veerapaneni, S.V., B. Klayman, S. Wang, and R. Bond. 2011. *Desalination Facility Design and Operation for Maximum Energy Efficiency.* Denver, Colo.: Water Research Foundation.

Verstraete, W., P. Van de Caveye, and V. Diamantis. 2009. *Maximum use of resources present in domestic "used water"*. Bioresource technology, 100(23), 5537-5545.

Von Meier, A. 1999. *Occupational cultures as a challenge to technological innovation*. Engineering Management, IEEE Transactions on, 46(1), 101-114.

VWEA (Virginia Water Environment Association). 2013. *WERF: Research on Sustainable and Re-NEW-able Resources – Nutrients, Energy, Water*. A Presentation for the VWEA Education Committee, 2013 Annual Seminar. Richmond, VA.

Wallis, M.J, M.R. Ambrose, C., and C. Chan. 2008. *Climate change: Charting a water course in an uncertain future.* Journal of American Water Works Association, 100 (6).

WEF (Water Environment Federation). 2009. *Energy Conservation in Water and Wastewater Facilities - MOP 32 (WEF Manual of Practice)*. McGraw-Hill Professional, 2009.

WEF (Water Environment Federation). 2012. *Energy Roadmap: Driving Water and Wastewater Utilities to More Sustainable Energy Management*. October, 2012.

Welgemoed, T.J. 2005. *Capacitive Deionization Technology: Development and evaluation of an industrial prototype system*. University of Pretoria, 2005, Dissertation.

Wiesner, M. 2013. *Direct Contact Membrane Distillation for Water Reuse Using Nanostructured Ceramic Membranes.* Water Reuse Research Foundation. WRRF # 07-05-1.

Wilcoxson, D., and M. Badruzzaman. 2013. *Optimization of wastewater lift stations for reduction of energy usage and greenhouse gas emissions*. Water Environment Research Foundation. Report # INFR3R11.

Wilf, M., L. Awerbuch, and C. Bartels. 2007. T*he guidebook to membrane desalination technology: reverse osmosis, nanofiltration and hybrid systems process, design, applications and economics*. Balaban Desalination Publications.

Wilf, M., and C. Bartels. 2005. *Optimization of seawater RO systems design*. Desalination, 173, 1 – 12.

Wilf, M., and J. Hudkins. 2010. *Energy Efficient Configuration of RO Desalination Units*. Proceedings of Water Environment Federation Membrane Applications Conference, Anaheim, California.

Willis, J.L. 2011. *Combined Heat and power system evaluation tool instruction manual*. Water Environment Research Foundation. Report WERF#U2R08b.

Willis, J., L. Stone, K. Durden, N. Beecher, C. Hemenway, and R. Greenwood. 2012. *Barriers to Biogas Use for Renewable Energy*. Water Environment Research Foundation. Report # OWSO11C10.

Willis, J.L. [N.d.] *Identification of Barriers to Energy Efficiency and Resource Recovery at WRRF's and Solutions to Promote These Practices.* Water Environment Research Foundation. WERF # ENER7C13. Forthcoming.

Yonkin, M., K. Clubine, and K. O'Connor. 2008. *Importance of Energy Efficiency to the Water and Wastewater Sector.* Clearwaters.

APPENDIX A
WORKSHOP AGENDAS

APPENDIX B
QUESTIONNAIRE

APPENDIX C
PROJECT RANKING

APPENDIX D
RESEARCH PROJECT DESCRIPTION